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Feasibility of Using Segmentation Techniques for the Enhancement of Marine Radar Images as Encountered in Ice Infested Waters

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16. Abstract

The chief objective of this project was to investigate the feasibility of using image processing techniques in order to enhance and segment the ice features present in marine radar images. To this end, various image enhancement and segmentation techniques have been selected for implementation. Enhancement methods based on linear and non-linear spatial filtering, frequency domain filtering, histogram treatment, thresholding, and mathematical morphology have been implemented and tested. The segmentation process was subdivided into two categories, namely, edge-based and region-based techniques. Edge-based segmentation methods include convolution with local operators, relaxation labeling on edges and curves, and contour tracing. Region-based segmentation techniques include clustering, relaxation labeling on clusters, quadtree, and region merging.

This feasibility study showed the suitability of using image processing techniques for the enhancement of marine radar image. The methods that have shown most promise are based on region-based segmentation. The edge-based segmentation methods, on the other hand, were more sensitive to the marine radar image noise, but they were found to be effective in visually enhancing the ice-floe features when applied after a region-based method. It is recommended to pursue further research and testing for the use of segmentation techniques for the marine radar images.

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16. Resumé

L'objectif principal de ce projet est d'étudier la faisabilité d'utiliser des techniques de traitement d'images pour mettre en valeur les floes de glaces présentes dans des images radars. Plusieurs méthodes de mise en valeur et de segmentation ont été développées. Les méthodes de mise en valeur sont composées de filtres spatiaux linéaires et non-linéaires, filtres en domaine de fréquences, traitement d'histogrammes, segmentation basée sur différents seuils d'intensité et morphologie mathématique. Les méthodes de segmentation sont décomposées en deux classes: segmentation basée sur les bords et segmentation basée sur les régions de l'image. La segmentation basée sur les bords présents dans l'image radar consiste à utiliser des méthodes telles que la convolution avec des opérateurs locaux pour déterminer les bords, la relaxation sur les bords pour accentuer l'apparence des bords ainsi qu'un algorithme de recherche des contours. La segmentation basée sur les régions utilise des méthodes de groupement d'objets, de relaxation sur les différents groupes, de division d'image en régions et de fusion des régions.

Cette étude de faisabilité a démontré que les techniques de traitement des images, pour la mise en valeur et la segmentation des images radars, sont convenables et prometteuses. La segmentation des régions a montré de meilleurs résultats que la segmentation basée sur les bords de l'image. Cette dernière est plus sensible au bruit, cependant son application après la segmentation sur les régions a montré des résultats très satifaisants visuellement. À cette étape du projet, il est recommandé de poursuivre les recherches nécessaires pour la sélection des méthodes de traitement d'images les plus convenables pour la segmentation des floes de glaces dans les images radars.

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Summary

The chief objective of this project was to investigate the feasibility of using image processing techniques in order to enhance and segment the ice features present in marine radar images. To this end, various image enhancement and segmentation techniques have been selected for implementation.

1- A Theoretical Study of the Marine radar images

This includes a statistical study of the different moments related to the marine radar image and to each ice floe. This helps in deciding if any intensity enhancement is needed for the whole image. At the same time, it provides more information about the ice floes that need to be enhanced.

2- Data Acquisition

This step involves image digitization and format coding for speed and space considerations.

3- Pre- and Post- Processing Software Development

This step involves the development of thresholding and filtering techniques. The thresholding techniques comprise the average threshold, Otsu's threshold, and histogram treatment techniques. The thresholding techniques are implemented in order to enhance and/or segment the image, based on the intensity information. The filtering techniques comprise the median, average, and frequency lowpass filters. All methods developed under the filtering techniques have as a goal to integrate the marine radar image in order to attenuate the effect of the scattered noise. This has, however, a secondary effect of blurring the clarity of the edges. A last pre-processing technique that is implemented in order to prepare the marine radar images for segmentation is mathematical morphology. This method is developed in order to remove small features by grouping together and unifying similar regions.

4- Segmentation Techniques

Segmentation is used in order to find regions (ice floes) in the marine radar images. This segmentation of the ice floes can be used for visual enhancement as well as for correlation with the SAR image. Two categories of segmentation are implemented, namely, edge–based segmentation and region–based segmentation.

Edge–based segmentation involves spatial edge detection with local operators (Prewitt, Sobel, Laplacian *etc.*). Edge enhancement can also be performed in the frequency domain. This involves the development of the Fast Fourier Transform, ideal and non-ideal filtering. Other transforms considered are the Hough transform and the Walsh–Hadamard transform. In order to further enhance the result of the edge detection process, a relaxation labeling scheme was developed in order to remove the inconsistent information and to strengthen the valid and supported information.

Region–based segmentation involves the implementation of clustering, quadtree, and relaxation labeling. Clustering is based on grouping together certain pixels of the image in order

to form uniform regions. These regions are grouped together in order to satisfy criteria that are determined to best correspond to the ice–floe features in the image. The quadtree is a region–splitting algorithm very similar, in essence, to clustering. The quadtree, however, should be followed by the region–merging algorithm in order to form the ice floes of the image. Relaxation labeling was implemented, in this case, in order to make the clustering techniques less dependent on the shapes defined by the similarity measures used in forming the regions.

Results and Recommendations

The feasibility study, as a whole, showed good results. Several algorithms produced promising results. Amongst the more successful 'high–level' algorithms are the quadtree, region–merging and relaxation–labeling. Clustering algorithms also demonstrated favourable results to warrant further study.

The general direction of research that the feasibility study indicates is summarized below. First of all, a wide variety of pre-processing algorithms had been developed. Although none produce good results in themselves, it is recommended that they all be kept. These algorithms are all basic to practically any image processing application and will inevitably be used in combination with higher–level algorithms. The edge–based algorithms, in themselves, did not produce favourable results, but we found them to be very effective in providing a visual enhancement of the marine radar images by applying them after a suitably chosen region–based algorithm. The region–based algorithms, as a whole, produced the most promising results in segmenting the marine radar images. This is partly explained by the nature of the marine radar images themselves. Thus the general direction that this feasibility study points towards is a concentration on region–based methods to provide a segmentation of the image, possibly followed by edge–based algorithms that would provide a visual enhancement of the images.

Sommaire

Le but de ce projet est d'étudier la faisabilité d'utiliser des techniques de traitement d'images pour mettre en valeur et segmenter les floes de glaces présentes dans des images radars. Plusieurs méthodes de mise en valeur et de segmentation ont été sélectionnées pour une éventuelle implantation.

1 Étude théorique des images radars

Cette section inclut une étude statistique des moments des floes de glaces dans les images radars. Au besoin, cette étude permet de mieux distribuer l'intensité dans une image; de plus, elle permet d'accroître nos informations à propos de la forme géométrique des floes de glaces.

2 Acquisition de données

Cette étape implique la digitalisation des images et le choix de formats en raison des contraintes de vitesse et d'espace mémoire.

3 Développement d'algorithmes pour la mise en valeur de certaines composantes des images radars

Cette étape comporte le développement d'algorithmes pour le choix de seuils ainsi que l'implantation de certains filtres dans les domaines temporels et des fréquences. Les méthodes de spécification de seuils comprennent les algorithmes de seuil moyen, de seuil d'Otsu, de seuil variable, et certaines méthodes de traitement de l'histogramme des images radars. Les algorithmes de spécification de seuils sont implantés pour mettre en valeur certaines particularités de l'image, ce qui permet de segmenter les images sous traitement en se basant sur l'information de l'intensité. Les techniques de filtrage qui sont implantées durant cette étape comprennent l'utilisation de filtres basés sur la médiane et sur la moyenne ainsi que des filtres dans le domaine des fréquences. Tous les filtres développés dans cette section ont comme but commun d'intégrer localement ou globalement l'image radar pour atténuer l'effet du bruit. Cependant, ces filtres passe–bas ont comme effet secondaire de brouiller l'image. Par la suite, l'utilisation des filtres passe–bas a été limitée au minimum. La dernière méthode de traitement, développée durant cette étape, est basée sur la morphologie mathématique. Cet algorithme est implanté selon deux façons: adaptative et absolue. Le but de cette méthode est d'éliminer certains bruits présents dans l'image en groupant et unifiant les régions qui sont jugées similaires dans les images radars.

4 Techniques de segmentation

La segmentation est une méthode de traitement utilisée pour trouver les régions présentes dans les images. Dans le cas des images radars, la segmentation peut être utilisée pour déterminer les floes de glaces et, par la suite, les mettre en valeur. La segmentation des floes de glaces dans l'image radar permet aussi la corrélation avec l'image SAR. La première méthode de segmentation est basée sur la segmentation des bords dans l'image. La seconde est basée sur la segmentation des régions.

La segmentation basée sur les bords implique le développement de détecteurs des bords tels que: Prewitt, Sobel, Laplacian, etc. La détection peut aussi être réalisée dans le domaine des fréquences, ceci implique le développement de la transformée de Fourier et des filtres passe–haut dans le domaine de fréquence. Certaines autres transformées, telles que la transformée de Hough et celle de Walsh-Hadamard, ont aussi été considérées. Aprés la détection des bords de l'image, un algorithme de relaxation sur les bords est développé pour essayer de connecter les bords séparés et pour éliminer les bords dispersés créés par les filtrages. Le résultat de l'algorithme de relaxation a ensuite été traité pour définir les contours des floes de glaces.

La segmentation basée sur les régions de l'image comporte l'implantation des variations de certains algorithmes tels que: classification supervisée et non supervisée des grappes, subdivision itérative des régions de l'image et relaxation sur les différentes grappes. La classification des grappes est basée sur le groupement des différents points de l'image pour former des grappes homogènes. Ces grappes (ou régions) sont formées pour satisfaire certains critères qui sont déterminés pour représenter le mieux possible les floes de glaces présentes dans l'image radar. Ces critères sont déterminés à partir de l'étude statistique. La subdivision itérative de l'image permet aussi sa segmentation. La méthode est assez semblable à la classification des grappes. Cependant, la subdivision des images radars doit toujours être accompagnée d'un algorithme de fusionnement de régions pour former les floes de glaces présentes dans l'image. La relaxation a été implantée dans cette section pour assurer la non–dépendance des grappes sur les formes géométriques que les critères peuvent imposer.

Conclusions et Recommandations

L'étude de faisabilité a montré des bons résultats. Les algorithmes qui ont montré les meilleurs résultats sont basés sur la subdivision itérative de l'image, regroupement des régions, et la relaxation sur les régions. Le regroupement des grappes basé sur des vecteurs représentants certaines caractéristiques de l'image a aussi montré des résultats encourageant.

En sommaire, l'étude de faisabilité permet de faire la conclusion suivante: En premier lieu, les méthodes de prétraitement des images n'ont pas produit des résultats finals, ils ont surtout préparé les images pour des traitement plus en profondeur. Tous ces algorithmes de prétraitement des images doivent être conservés à cause de leur utilité dans la plupart des applications de traitement d'images. La segmentation basée sur les bords de l'image quand appliquée sur les images radars n'a pas montré des résultats favorables. Mais ce genre de segmentation a montré une bonne mise en valeur visuelle des floes de glaces une fois qu'une segmentation des régions a été appliquée. La méthode de segmentation des régions des images radars a montré les meilleurs résultats pour déterminer et définir les floes de glaces présentes dans l'image. Par la suite, la direction de cette recherche doit concentrer surtout sur la segmentation des régions pour définir géométriquement les floes de glaces. Ceci servira pour le but final du projet qui est de retrouver les floes de glaces de l'image radar et les reconnaître dans l'image SAR.

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1. Introduction

Despite the advancements in the Shipboard Ice Navigation Support System (SINSS), a number of deficiencies have been identified by the Transportation Development Centre (TDC) and Canarctic Shipping Ltd. These deficiencies occur in two major categories: the first concerns the difficulties associated with the interpretation of the marine radar image, and the second concerns the manning and training of the navigation officers. It is the purpose of this project to address the first category of deficiencies.

The most difficult aspect of tactical navigation using SAR is the correlation of recognizable features between the marine radar image and the SAR image itself. One recommendation from the 1987 Phase V of SINSS is to investigate various methods of improving the quality of the MARINE-VUE display through signal processing. The techniques examined for the enhancement of the marine radar images included three major categories: Pre-processing and post-processing of images, edge–based segmentation techniques, and region–based segmentation techniques.

The actual problem suggested by Canarctic Shipping and TDC is presented as follows: there are two images available onboard, the first is the marine radar image (figure 1) and the second is the SAR image (figure 2) of a certain area; the task is to recognize features in both images in order to position the ship on the SAR image.

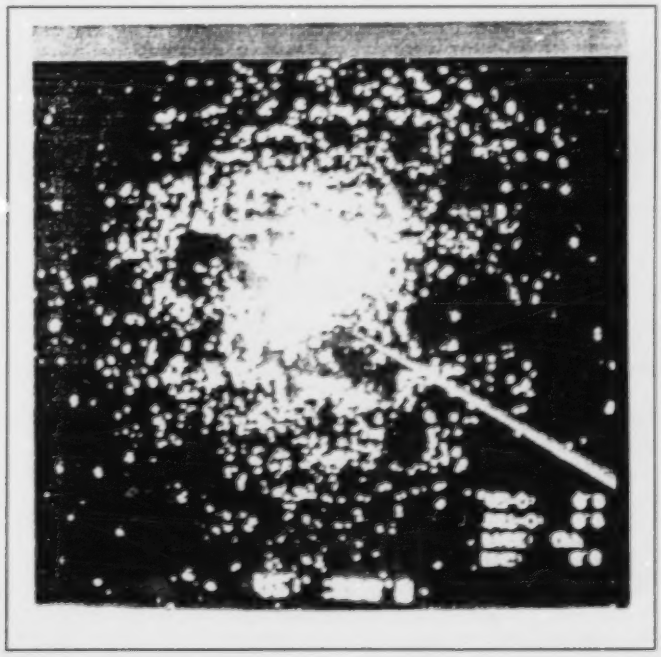

Figure 1 A Typical Marine-Vue Image

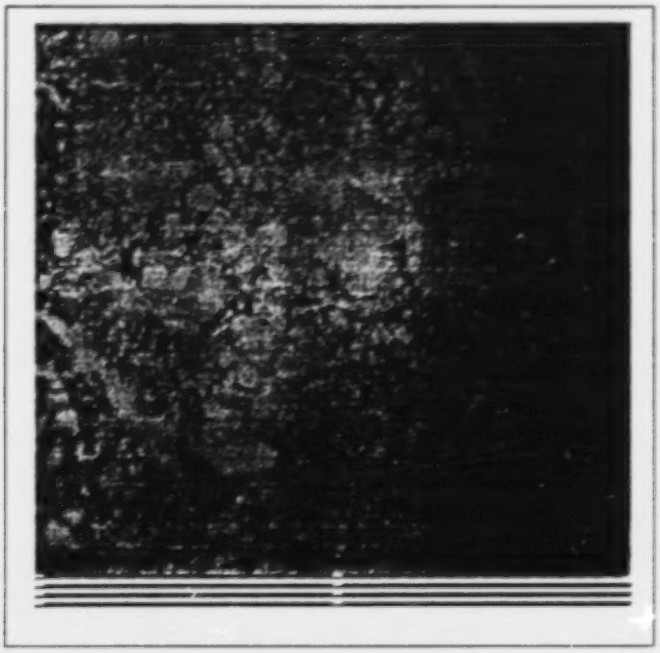

Figure 2 *Corresponding SAR Image*

The features' recognition is performed by an experienced operator. The marine radar image, however, is so unclear that the probability of the operator making a judgement error is relatively high. This misjudgment can result in many problems such as a deviation from the desired navigation path, or the ship being trapped in major ice floes.

The chief objective of this project is to determine the feasibility of using image enhancement and segmentation techniques to aid in the year–round navigation of Canadian Arctic waters. The feasibility study consisted of studying and testing several image enhancement and segmentation algorithms and assessing their effectiveness in highlighting salient features in the marine radar images. In this report, we present and discuss the algorithms that were developed and tested during this phase of the project.

2. General Pre-processing and Post-processing Techniques

To begin the project, various image handling techniques were developed. These include read, write, insert, delete, exchange, scale, translate, rotate, range normalize and various other facilities. A user interface was also developed and consisted of commands that can be invoked from nested menus using the mouse or from the keyboard, using a 'key–tree matcher' at the command entry level. We will not further explain these routines, as they were developed only to conduct the trial of different techniques on the radar images, and served as only an aid in the development and testing of the image processing algorithms.

After developing the facilities to manipulate the images, we have implemented several basic routines to learn more about the images at hand. These routines included facilities for statistical analysis, histogram treatment, thresholding, filtering, and morphology.

2.1 Statistics

The statistical analysis included an analysis of the two first moments of the image as well as the moments related to ice floes in the image. This was done in order to have more information about how the ice floes appear on the radar image. As an example, this analysis confirmed the fact that the waves of the radar reflect off the ridges determining the ice floe rather than the surface of the ice floe itself. Therefore the marine radar image does not contain enough information about the ice floe's surface. This is obviously different from the SAR image which contains the necessary information about the surface of the ice floe.

2.2 Histogram Treatment

The histogram gives the necessary information about the concentration of pixels at a certain grey level. This information is useful in order to decide for the best thresholds to use or to better distribute the grey levels within the image (histogram equalization.) In the case of the marine radar images, equalizing the histogram did not present significant enhancement.

We know at this point that the marine radar image will not present an enhancement if only the intensity of the image is considered, in other words the marine radar image is not suitable for segmentation based on thresholds. The next section will further demonstrate this fact.

2.3 Thresholding

The marine radar images are composed of a large number of dot-clusters. This tended to define regions of similar dot-density, but because of the irregularity of the dot spacing and the large number of breaks, the boundaries between the regions are ill-defined. Moreover, the statistical study revealed that the inside of the ill-defined boundaries do not present any uniform or at least slowly varying grey levels. However, the boundaries appear as if they are of uniform grey level. In order to test the possibility of enhancing or segmenting the image based only on the fact that the ridges are of a relatively uniform grey level, we implemented the following thresholding techniques.

Let $f(m,n)$ be the function representing the radar image and let $g(m,n)$ represent the resultant image after a certain operation. Segmenting $f(m,n)$ based on multiple thresholds only means that all the existing grey levels of the original image are grouped together to form fewer and hopefully more uniform grey levels at the boundaries. This typical thresholding scheme did not, however, present good results. Otsu's thresholding techniques for the selection of one or more thresholds was then used. We chose this method because of its robustness to noise. The result is shown below for one threshold selection:

Figure 3 Otsu's Threshold on the original image

Obviously, the resulting image is not desirable. Therefore our efforts to enhance or segment the image based on multiple thresholds stopped at this point, and another alternative was pursued further.

This alternative is based on thresholding applied to the gradient image. The gradient image is the resulting image after applying a differential operator to $f(m,n)$. The differential operator has the effect of keeping the changes in intensity in the image, namely, the edges. As explained earlier, the marine radar image does not present uniform intensity in the ice floe surfaces but presents a relatively uniform intensity at the ill-defined boundaries. The problem that we had to face applying this method is the fact that the marine radar images are rather noisy and only a convolution with a differential operator does not result in well defined edges, therefore, the thresholding had to be adaptive and smoothed. Adaptive thresholding is applied on gradient images in order to choose the threshold value selectively, based on different windows. Before

choosing the adaptive threshold, a partial integration (lowpass filter) over the window of interest is performed in order to assure the smoothness of the window where the threshold value is to be selected [Kohler, Robinson].

The result of a local adaptive lowpass thresholding is shown next:

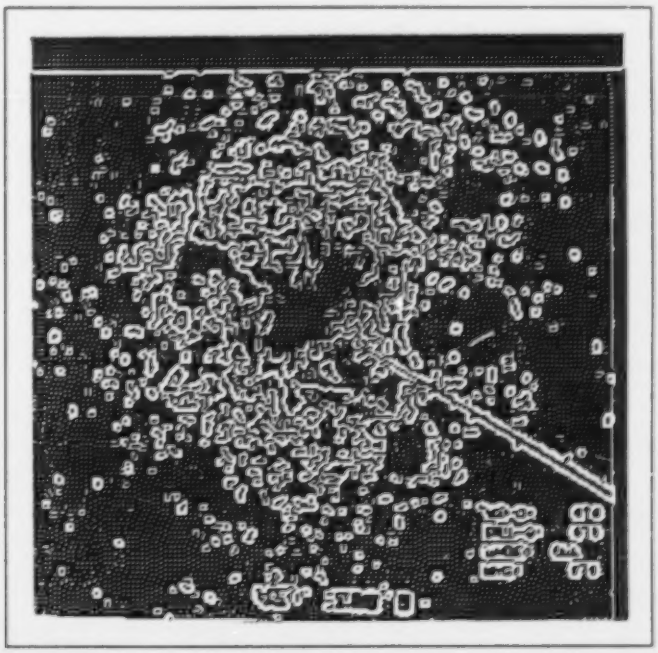

Figure 4 Low Pass Adaptive Threshold 3×3 on the Gradient Image

This is obviously a disappointing result. Thresholding the raw or the gradient images did not seem, at this stage, to improve or even promise an improvement for the marine radar images. At this point in the project, we decided not to further investigate segmenting the marine radar image using only the grey–level information.

2.4 Filtering for Pre-processing

As was mentioned earlier, the marine radar images are very noisy. Some image segmentation techniques are quite sensitive to noise and therefore, with a pre-processing step, the noise should be attenuated. The so–called noise is defined as any undesirable information in the image. The noise in the marine radar information can be due to sea clutter, circuitry, logarithmic amplification of signals *etc.* In the case of the marine radar image, the ice floe is determined by its contour. Because of the geometric configuration of the radar, however, the naturally closed contour can be obscured. This was considered as noise during the enhancement of the marine radar images. The different techniques developed at this section are aimed at attenuating the

effect of different types of noise in order to make the marine radar image suitable for further processing.

This section describes two types of filtering, namely, spatial and frequency domain filtering. The spatial domain filtering are more desirable in most image processing applications, because of the fact that they are more easily controllable since they can be modified to take into account neighborhood information. Frequency domain filtering is performed in the transform domain. It presents an advantage over spatial domain filtering in two circumstances. The first is due to its simplicity when one or many known frequency components have to be eliminated such as in the elimination of the power line frequency component. The second advantage can be speed, this is apparent when the image has to be smoothed very much; in this case, smoothing in spatial domain can be very lengthy because of the large size of the needed operator.

2.4.1 Average Filtering

The average filter is a two dimensional discrete integrator. This filter has the effect of lowpassing the image, thus eliminating or attenuating the scattered first type noise. The average filter has one parameter which is the window size. If the window size is too big, the resulting image tends to be fuzzy. It was found that in the case of radar marine images, the window size should be kept to minimum (*i.e.* 3×3). The result of the application of a 3×3 average filter is shown below:

Figure 5 Average Filter 3×3

The operator for the average filter is:

$$\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

As expected, the average filter has attenuated the scattered noise since it is a spatial lowpass filter. The average filter, however, has secondary effects. Since the high frequency components of the image contain the scattered noise as well as the edges defining the ice floes, the ice floe definition becomes fuzzier after the application of the lowpass average filter. A better alternative for the smoothing of the marine radar image was then sought.

2.4.2 Median Filter

The improvement of noisy image signals by means of space invariant lowpass filters operations is only a compromise between the suppression of the noise superimposed on the image and the retention of the fine detail. An operator which largely avoids this disadvantage is the median filter. With this filter, the p elements inside a local operator window are stored by value. The resultant output image element is the $(p+1)/2$ highest value of the series. This process completely eliminates all structures whose extent inside the operator window is less than $(p-1)/2$ pixels. However, the bright edges do not lose very much sharpness as in the case of the average filter. The size of the window is important—in the case of the marine radar images and after many trials, we found that the size should not exceed 5×5 in order to keep enough detail. The results of 3×3 and 5×5 median filters are shown below:

The median filter showed to be quite useful as a pre-processing technique since there is less scattered noise and enough information about the edges of the ice floes are kept for further processing.

2.4.3 Edge Preserving Smoothing

The simplest smoothing operator generally used in image processing is the average filter. This is simply a convolution mask that contains one's as elements. Thus the average filter operates by setting each pixel in the image to the average value of the neighboring region. This has the effect of smoothing out small and spurious features in the images. It also, however, has the undesirable effect of blurring sharp edge–features and boundaries in the image. Since every pixel is set to the average value of its immediate neighborhood, the pixels that lie near discontinuities in intensity (*i.e.* edges) will have a new intermediate value.

The edge-preserving filter attempts to take this into account when it calculates the new 'smoothed' value of the pixel. Instead of looking at just one neighborhood, the edge-preserving method considers nine regions. Eight regions are in the eight compass directions around the

Figure 6 Median Filter 3 × 3

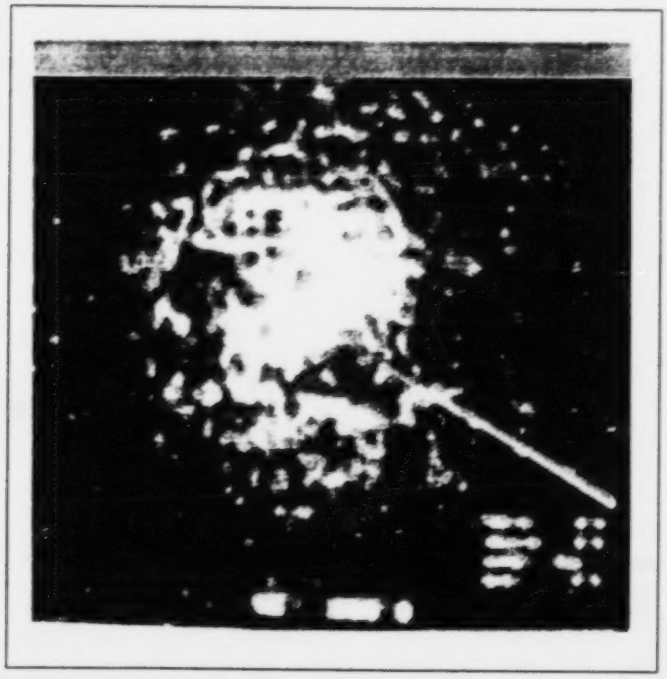

Figure 7 Median Filter 5 × 5

pixel and the ninth region is the same that is used by the average filter (*i.e.* the immediate 3×3 neighborhood). The edge–preserving filter uses a simple heuristic to determine the most appropriate average value for the pixel: In each of the nine regions, the variance is calculated. The region with the minimum variance is chosen and the pixel is assigned the average value of that region. The reason behind this is that the variance signifies the amount of change in a region. An area that has an almost constant intensity will have a very small variance, while region that contain sharp changes in intensity (*i.e.* edges) will have a high variance. Thus by always smoothing over the neighborhood region of minimum variance, edge–features in the image are retained.

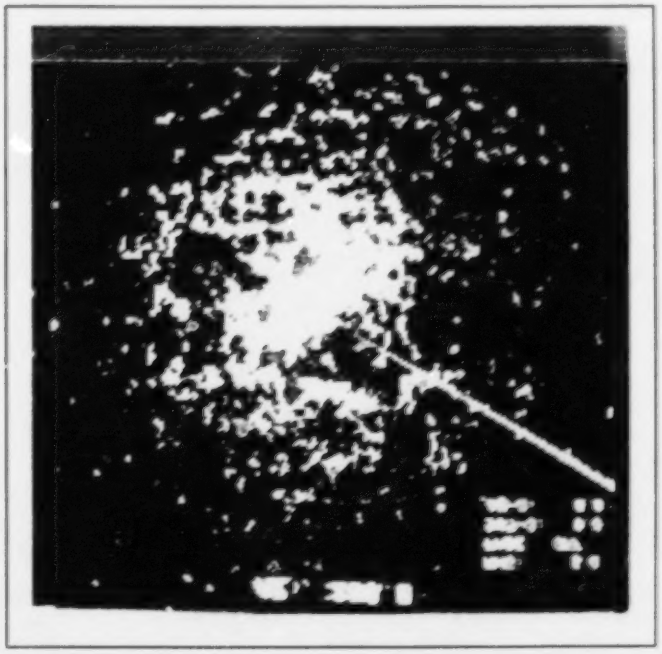

Figure 8 Edge Preserving Filter 5×5

The edge preserving filter seemed to show good results on all tested images. Good results, meaning that the scattered noise is attenuated while enough information about the contours of the ice floes is kept.

2.4.4 Frequency Domain Smoothing

The frequency domain lowpass filtering is yet another way of smoothing the marine radar image. This technique of smoothing has disadvantages and advantages. Its major advantage is the fact that it is rather easy to implement in hardware especially in the case of the Fourier domain. Frequency domain filtering is interesting when tremendous smoothing is needed, because in this case, spatial smoothing is rather lengthy. Frequency domain filtering has

however one major disadvantage, namely, the fact that it is global and therefore is not based on neighborhood information. There are many domains to which an image can be transformed in order to be treated with frequency domain filtering techniques. We chose the Fourier domain because we believe that it is the most suitable for the objects to be enhanced at hand namely, ice floes. Other domains can be chosen if the objects to be found or enhanced present very sharp changes, in which case, the Fourier domain is not very suitable—in the Fourier domain, sharp changes produce components at high frequencies. Therefore more computation is required to be able to map the object properly and approximate it with the minimum amount of components in the transform domain. Truncating the Fourier coefficients results in the so-called "Gibb's effect" which, roughly speaking, corresponds to a "ringing" in the areas of sharp change.

For the end of frequency domain smoothing, an FFT algorithm was implemented and a simple ideal lowpass filter resulted in the following image:

Figure 9 Frequency Domain Ideal Lowpass Filter

2.5 Mathematical Morphology

This method essentially involves repeatedly expanding and contracting an image locally [Serra]. This has the effect of removing small features by grouping together and unifying similar regions. This algorithm is developed in order to better connect the edges defining the ice floes and eliminate the scattered noise in the image. As mentioned earlier, the marine

radar images do not present well defined boundaries and therefore a method like morphology is necessary before applying edge–based techniques. In general, the expansion is applied before the contraction on the image. In the case of a grey level image, this involves setting all the neighborhood of a certain pixel of the image to the maximum grey level found within the neighborhood window. The contraction sets the neighborhood to the minimum value. This algorithm is conducted in parallel and is very suitable for hardware implementation. The next figure shows the effect of the expansion-contraction algorithm on the original images.

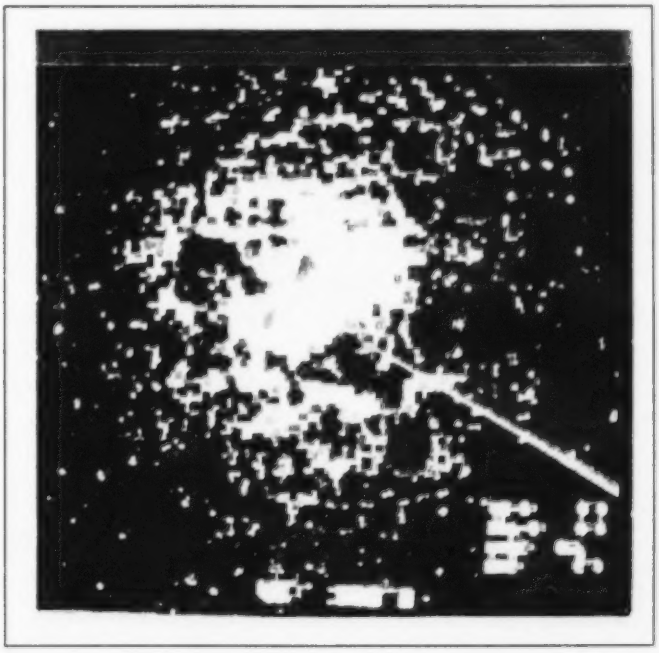

Figure 10 1 Expansion and 1 Contraction

At this stage, the algorithm needs an interaction with the user to know the sequence of contractions and expansions to be applied to the image. The biggest disadvantage of this algorithm is the fact that it is difficult to define an automatic manner to determine adaptively the sequence to be followed on a given image. Therefore, during the final implementation, a predefined sequence will always be used. This predefined sequence will be chosen based on the trials to be conducted during the next phase of the project.

2.6 Summary of the Results Obtained from Pre- and Post- Processing Methods

It was found at an early stage of the project that the marine radar image should not be segmented using only grey level information and hence we decided not to employ any thresholding procedure in order to enhance the images at hand. Moreover, methods based on

histogram treatment such as equalization or hyperbolization did not show good enhancement on the marine radar images. Because of the noisy nature of these images, smoothing procedures have been investigated. The result was that the marine radar images are not suitable for frequency domain filtering but some spatial domain smoothing have shown encouraging results. The two methods that showed good smoothing results are median filtering and edge preserving filtering.

3. Image Segmentation

The aim of image segmentation is to divide images in several meaningful areas. With image segmentation, objects of interest can be extracted and submitted to further analysis or interpretation. Thus image segmentation represents an important early stage in image analysis and identification. Image segmentation can either be complete or incomplete. Complete image segmentation is usually based on segmentation using region–based techniques. Edge–based segmentation techniques, however, lead to incomplete image segmentation, as will be explained later. The region–based image segmentation have the advantage of being robust to noise, but present a certain technical difficulty that is explained later in the report. The edge–based segmentation techniques, on the other hand, are easier to implement and lend themselves rather well for hardware implementation. The image segmentation techniques in general were applied to marine radar images in order to separate and identify the existing ice floes in the image in order to be able to recognize them on the corresponding SAR image.

3.1 Segmentation Based on Edge Techniques

In general, edge–based segmentation is a two stage process. First every image pixel is assigned a gradient value which is obtained from an edge detector. This gradient can be vectorial, where both the intensity and the direction of the edge are considered. After the first stage, the resultant image is an incomplete segmentation of the original image. The second stage involves a contour tracing algorithm in order to connect the scattered edges in a valid manner and produce closed contours determining the ice floes existing in the marine radar image.

For the first purpose of generating the gradient image, different methods of local gradient operators have been implemented and tested. The edge detectors are, however, differential which tended to enhance the scattered noise as well as the edges. A relaxation labeling procedure was, therefore, developed in order to enhance the edges and eliminate the scattered noisy features. After the application of edge detection and after enhancing the resultant image using a relaxation labeling scheme, a contour tracing algorithm will have to be implemented in order to separate the different regions of the image.

3.1.1 Edge detectors

The simplest edge detectors are based on convolution masks. To begin, the simplest edge-detecting operator is the Prewitt operator [Prewitt]. The operator is a discrete approximation

of the first directional derivative or gradient of a two dimensional function. At the boundaries present in the image, there is a change in intensity. Thus, the gradient at that point, in the direction of the edge, is relatively high. The Prewitt operator is directional, that is to say, its response depends on the orientation of the edge. If the edge is aligned to the axis of the mask, the response is maximal. There are eight 3 by 3 Prewitt masks, corresponding to the compass directions North, NorthEast, East, SouthEast, South, SouthWest, West and NorthWest. Note that the edges are further distinguished depending on whether the transition at the boundary is from light to dark or from dark to light. The edges in the image are located by looking for the local maxima of the operator output. The 3×3 Prewitt operator for a vertical edge with a normal in the easterly direction is:

$$\begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix}$$

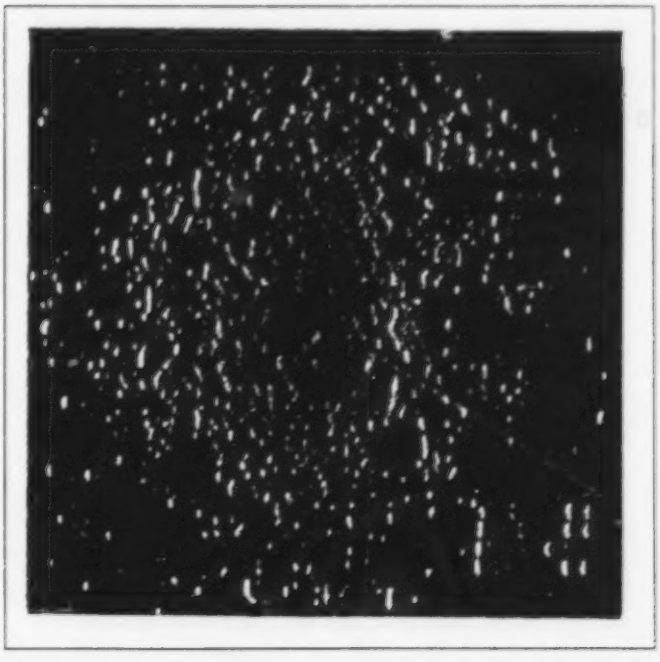

Figure 11 Effect of the 3×3 Vertical Prewitt Operator on the Original Image

The above image is the result of applying the Prewitt vertical operator on the image. In our case, however, we are not only looking for vertical edges but rather all edges. There are many ways to regroup the output of directional operators in order to generate all edges [Duda and Hart].

The Sobel operator is also an approximation to the first derivative. The Sobel operator, however, gives more weight to the pixels that are closer to the centre of the mask. This is generally more robust than the Prewitt operator. Since it too is a first degree differential operator, the edges in the image are located by looking for the local maxima in the convolved image. The 3×3 Sobel mask corresponding to a vertical edge with an eastward pointing normal is:

$$\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$$

The next figure shows the result of applying the sobel operators in the eight possible directions and combining the result in order to compute the "magnitude" of the operator.

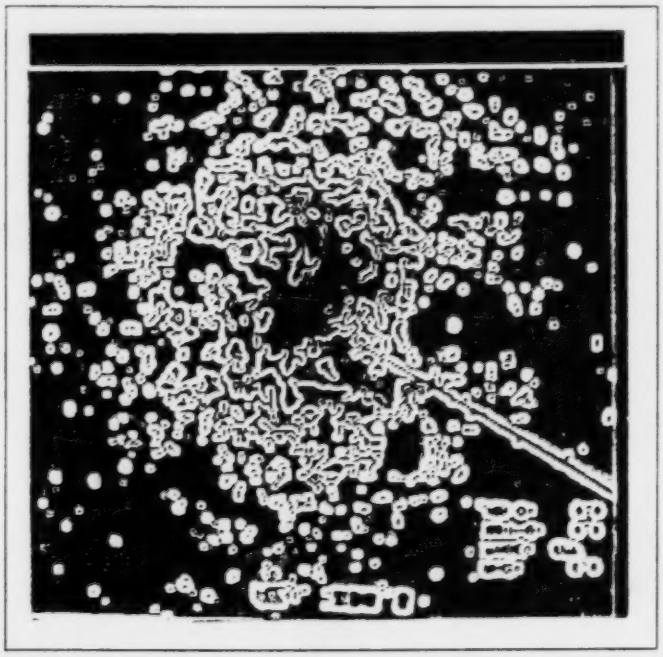

Figure 12 Sobel Operator 3×3 from the Original Image

There are many other operators [Roberts, Duda and Hart] which are based on the same ideas: approximation of the first directional derivative and changing the weights corresponding to the neighbors of the pixel under treatment. Many of these operators have been tried for different sizes on the marine radar images. But the results were rather similar to the Prewitt or Sobel operator; therefore, we will not present all results in this report.

The next logical progression in edge operators is the second degree differential operators. The idea behind these operators is the following: When a simple differential operator, such

as the Prewitt or Sobel operator, is applied to an image, one must find the local maxima in the image in order to locate the edges. The most common way to find the local minima or maxima of a function is to differentiate the function and look for the zero crossings. Thus, to find edges in an images, one has to locate the zero-crossings obtained by convolving the image with a second derivative operator. The Laplacian is the most commonly used operator of this sort. The 3×3 Laplacian mask is:

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

The Laplacian, unlike the Sobel and Prewitt operators is isotropic—its output is independent of the direction of the edge. The result of finding the zero crossings of the Laplacian applied to a marine radar image is given below.

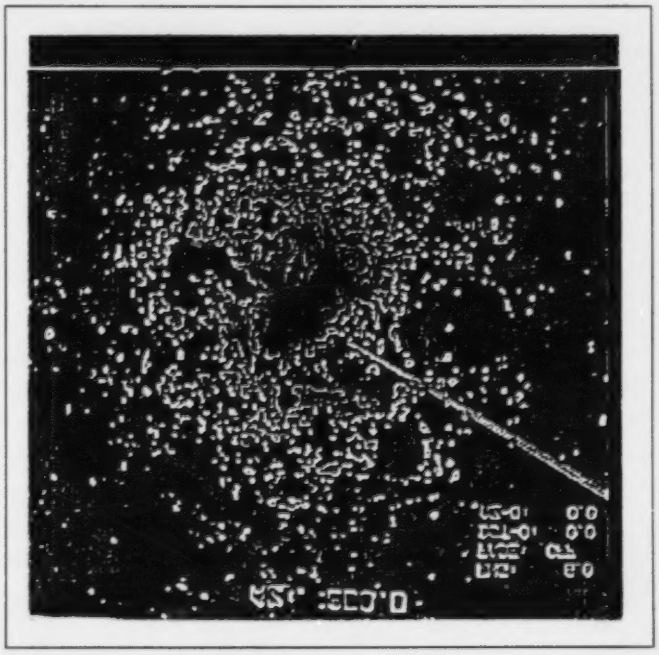

Figure 13 3×3 Laplacian from the Original Image

Other extensions of operators have been developed by researchers in the area of image processing. We implemented the ones we believed can be useful for the this project. As an example the bi–Laplacian approximates the fourth derivative instead of the second derivative. The reason for using the fourth derivative is to sharpen the convolved image. The bi–Laplacian, however, is much more sensitive to noise since it involves higher derivatives. Hence, it is less suitable for the raw marine radar image. The effect of the bi–Laplacian applied to a marine radar image is shown below.

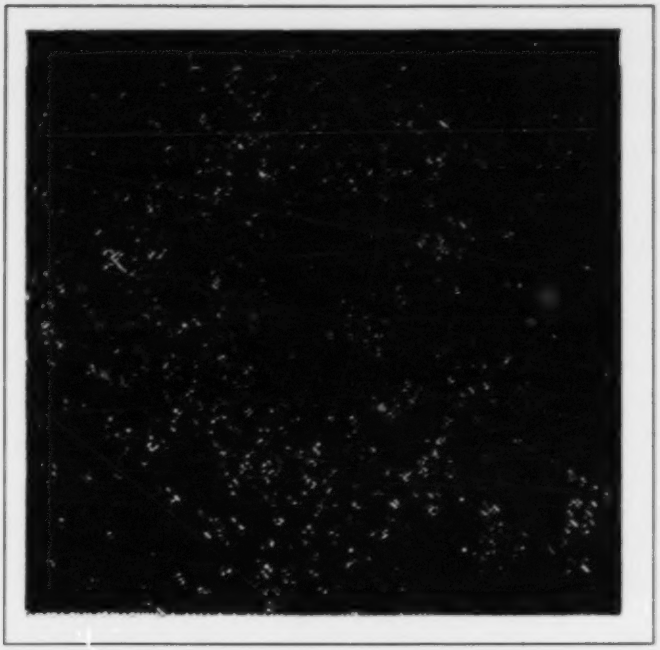

Figure 14 3×3 bi–Laplacian from the Original Image

The above shown images have all been obtained by applying one operator on the original image. This is, however, not useful since as mentioned above, the radar images are quite noisy and therefore, further differentiation would enhance the edges well as the scattered noise. Some combinations of the developed algorithms have to be combined together carefully in order to ensure a better treatment of the image. As an example, an edge preserving smoothing filter is applied to the original image. This has the effect of smoothing the image but keeping a sharp change in intensity across the edges. The edge preserving filter has to be of medium size, because a small size will cause almost a direct differentiation and a big size can cause smoothing without any care taken at the edges. After the edge preserving filter, a median filter is applied to smooth the result for the upcoming Laplacian differentiation. The result of the procedure is shown below; it is clear that this is a better gradient image than the one obtained by applying the Laplacian directly on the original image.

3.1.2 Transform Methods

Another broad class of edge–based image enhancement techniques is based on transform methods. The purpose behind analyzing the transform of an image (or any function, in general) is that in the transform domain certain features become more explicit. The Fourier transform is the most commonly used and most studied transform technique in image processing. One of the major reasons behind the popularity of the Fourier transform is the FFT algorithm, which permits the rapid computation of the transform. Edges in an image correspond to sharp

Figure 15 3×3 Laplacian Applied on a Pre-processed Image

changes in intensity within a small area in space. In the frequency (or Fourier) domain, this corresponds to the presence of energy in the high frequency components. The low frequencies in the transformed image correspond to slowly varying features in the image. Thus to enhance the edges in the image, the high frequency components are amplified with respect to the low frequency components; that is to say highpassing the image. The inverse Fourier transform of the highpassed image produces an image whose high frequencies (and hence edges) are emphasized. The result of ideally highpassing the marine radar image, in order to enhance the edges is shown below.

Besides using an ideal highpass filter, a homomorphic filter was tried, the results were similar. There is, however, a problem with using frequency–based methods, namely the fact that these methods are global. It is not possible to tune the high pass filter to take into account local features. In addition, highpassing an image tends to accentuate noisy features, which is undesirable for the marine radar images. Moreover, it is rather difficult to decide on the cut-off frequency of the filter since the decision should not only be based on the amplitude of the Fourier components of the marine radar image but also on the phase of the components. Many trials have been performed, and the global highpassing in the frequency domain did not promise good results and showed the undesirable and expected Gibb's effect. There are other transform methods that could have been applied on the marine radar images. However, as was found earlier for lowpassing the marine radar image, the Fourier domain is most suitable.

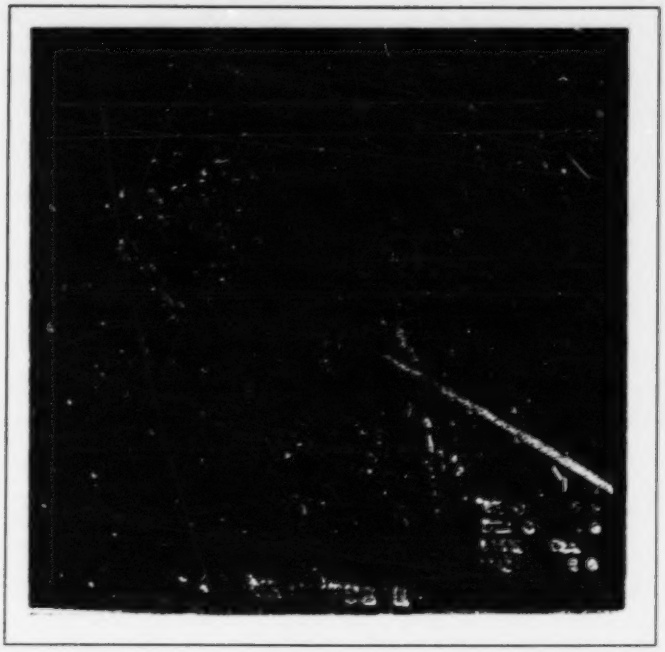

Figure 16 Highpass Global Filter applied on the Original Image

3.1.3 Relaxation Labeling on Edges and Curves

In order to enhance the result of edge detection, a relaxation labeling on edges and curves scheme was developed. Relaxation labeling is a very general procedure that has been applied to a wide variety of problems, not limited to image processing. The purpose of the algorithm is to assign an unambiguous label (out of a set of N labels) to the objects (pixels in the case of an image). The labels, in effect, correspond to a symbolic representation of the pixels.

In the case of relaxation applied for the enhancement of curves and edges, these labels correspond to the probability that a line segment passes through a point [Rosenfeld, Rosenfeld *et al.*, Mackworth]. In the method implemented, we distinguish between lines in the four directions: '|', '/', '–' and '\'. In addition, there is the label that no edge passes through a point. Note that we ignore the 'direction' of the edge, so there are 5 labels in altogether.

Initially, each point is assigned a probability that has one of the five labels. This initial guess is obtained by applying the simple Prewitt convolution mask over the image. Recall that the Prewitt operator is a gradient operator that responds strongly to an edge that is oriented along the axis of the operator. If the operator corresponding to a certain direction gives a strong response at a point in the image, then the label that corresponds to that direction is given a high probability.

Once the initial probabilities have been assigned, the algorithm proceeds in an iterative and parallel fashion. The probabilistic labelings at each point are updated, based on the labels of its neighbors. This updating is done in parallel for each point in the image, and is based on two

functions: the neighborhood function and the compatibility function. First, the neighborhood function gives the 'importance' of the neighboring points, in terms of a weight. The neighbors that are closer to the point in question are given a higher weight than those that are further away. The neighborhood function has to be determined experimentally. The neighborhood of a point is usually limited to a range of 3×3 to 11×11. The larger neighborhoods have a disadvantage of slowing down the algorithm, while small neighborhoods cause the relaxation process to converge slowly.

The second function, the compatibility function, deals with the interactions between the labels themselves. The effect of the compatibility function is to cause pixels with the same label to support each other, while mutually inhibiting pixels with different (or incompatible) labels. When applied to the marine radar images, this smooths and enhances linear features in the image.

The application of relaxation for edge and curve enhancement is illustrated with the following small example. Suppose, a point has some probability of having a label that corresponds to an edge in the direction, '|', but its neighbors have high probabilities for the label '–'. The effect of the compatibility function would be to increase the probability for that point having a label '–', while decreasing the probabilities for the other labels. In effect, the compatibility function indicates that if two pixels have similar labels, they are compatible, and thus mutually strengthen the probability assignments for that label. Conversely, if a point has a much different label than its neighbors (as in the above example), it is incompatible with their labelings Thus the probability of the inconsistent label will be reduced in favour of that of the consistent label.

Because of its explicit use of compatibility functions and larger neighborhood operations, the relaxation–based method of edge-enhancement is much more robust than most other edge–based techniques. In fact, since the compatibility functions can effectively be used to resolve ambiguities in the image, the method also has the effect of reducing uncorrelated image noise since they will not be supported by their neighbors. Relaxation applied for the enhancement of edges and curves is also particularly suited for the marine radar images since the boundaries are ill-defined. The relaxation process will have the effect of 'closing' the boundaries in the image. The effect of relaxation on the image, after two iterations is illustrated below. We should point out, however, that the relaxation labeling algorithms has many parameters attached to it, and many variations of the algorithm will have to be performed in order to realize the best result possible. In the following figure, points that are light have a high probability that there is no edge passing through them; dark points indicate that they are on a border.

3.1.4 Summary of the Results Obtained from the Edge–Based Techniques

The biggest problem related to convolution masks is the fact that they are sensitive to noise. This is so, because the convolution masks approximate the differentiation over a certain neighborhood of the image. In order to improve the result produced by a convolution mask,

Figure 17 Relaxation Labeling on Edges and Curves Applied on the Original Image

we apply relaxation labeling on edges and curves. By taking into account neighborhood information, and using conditional probabilities (in the form of compatibility functions), relaxation is able to reduce noise and ambiguous labelings in the image. However, in order to effectively use relaxation, there are many parameters that must be fine tuned. One step that is important to the process is the initial 'guess' that is used to start the relaxation. The method used for the initial guess, must be chosen after examining the effect of applying various edge detecting operators on the image. In addition, the compatibility function, which relates the effect of one label on neighboring labels must be chosen through experimentation. This will need experimentation over different images and will be conducted during the second phase of the project. For this reason, the contour tracing algorithm needed to fully segment the marine radar image was not developed at this stage.

To conclude, of the algorithms explained above, relaxation labeling for edge and curve enhancement is the most complex and yielded the most favorable results when applied to the original marine radar image. The results obtained after relaxation were not suitable enough in order to apply contour tracing for the segmentation of the image. We also found that the marine radar images are not suitable for frequency domain processing as these methods are global and do not include any explicit control over the neighborhood information at a pixel in the image.

3.2 Region–Based Techniques

The region–based approaches use a different methodology than the edge–based approaches

to perform the goal of image enhancement. Edge–based approaches rely on a change in the intensity of the image in order to segment it and find the borders of the change. Because of their nature, the edge–based approaches are sensitive to noise and tend to enhance the noise as much as the desired edges. Therefore, a noise treatment is always necessary before or after any edge–based segmentation technique as shown previously. On the other hand, the region–based techniques are more robust to noise and their result is very suitable for contour tracing, if desired.

There are four major methods of region segmentation that were implemented, namely, clustering, relaxation on clusters, quadtree, and region merging. Clustering (region growing), quadtree (region splitting), and region merging are all based on determining the different regions of the image based on some measures named feature vectors. Each pixel has a feature vector corresponding to it, in the feature vector we can incorporate information such as the placement, grey level, similarity with neighborhood and others. The feature vectors are then classified using a certain measure of similarity. Similar feature vectors define the distinct regions associated with the image based on the components chosen for the feature vectors. The relaxation labeling on clusters is not a region segmentation method but is used for reasons to be explained later.

Next, we will explain without getting into mathematical details, the implemented region–based techniques, we will also evaluate them and discuss their advantages and disadvantages.

3.2.1 Clustering

Clustering is a general scheme that groups together feature vectors in a feature space. The feature vectors are always grouped together under a minimum distance measure. We should mention, however, that cluster seeking is an experiment-oriented algorithm because the performance of a given clustering algorithm is not only dependant on the type of image being processed but also strongly influenced by the components of the feature vectors chosen to be analyzed. The best components to consider in the feature vectors can only be determined after extensive trials. To update a cluster, it is necessary to define a rule (measure of similarity) to assign feature vectors to the domain of one cluster or another. The measure of similarity that we considered is based on the Euclidean distance of the feature vector to be processed and the feature vector defining the centre of gravity of each existing cluster. The components of the feature vectors that are considered have a major effect on the success or failure of the clustering algorithm. The idea of clustering is very simple once a decision is made about the data to be clustered and the measure of similarity to be used; it suffices to group together the closest (minimum distance) feature vectors in the feature space. We have developed two clustering algorithms, namely, K-means and Isodata [Duda and Hart]. They are very similar in nature, the major difference between them is in the final number of clusters that are sought in an image. The K-means algorithm will force the final number of clusters to meet a pre-specified evaluation set by the user. This is not a problem as such, because a region or cluster merging algorithm can be applied and the desired number of clusters specified for the K-means algorithm can then be specified quite high. The Isodata algorithm has a goal of a certain pre-specified number of clusters but can converge before attaining that goal if there are no changes in the number of

feature vectors of the clusters between one iteration and the next.

The K-means algorithm is composed of four steps:

1 - Choose the initial cluster centres.

2 - Distribute all the feature vectors between the cluster domains based on the similarity measure.

3 - Update the new clusters centres.

4 - if there is no change in the distribution of feature vectors, then it is the end of the algorithm, otherwise repeat from step 2.

The Isodata algorithm is almost constructed of the same basic steps. It adds however some splitting and merging between the steps. If a cluster composed of a certain number of feature vectors presents a relatively high standard deviation over the components of the feature vector, it is then broken down to two clusters in order to minimize the standard deviation of both of them. The merging step consists of merging two clusters if they are similar to a certain cluster-dependant degree.

As we have mentioned earlier, the choice of the components to consider for the feature vectors is very crucial to the success of clustering and can only be determined after many trials on different images. As a starting point, we only considered the position and the intensity of the a pixel as the components of its representing feature vector. The results are shown in the next figures for the K-means algorithm:

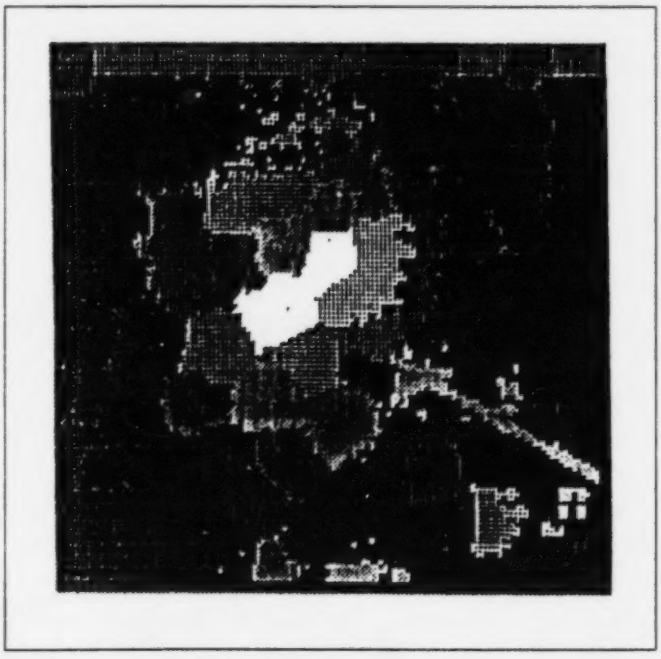

Figure 18 K-means After 2 Iterations

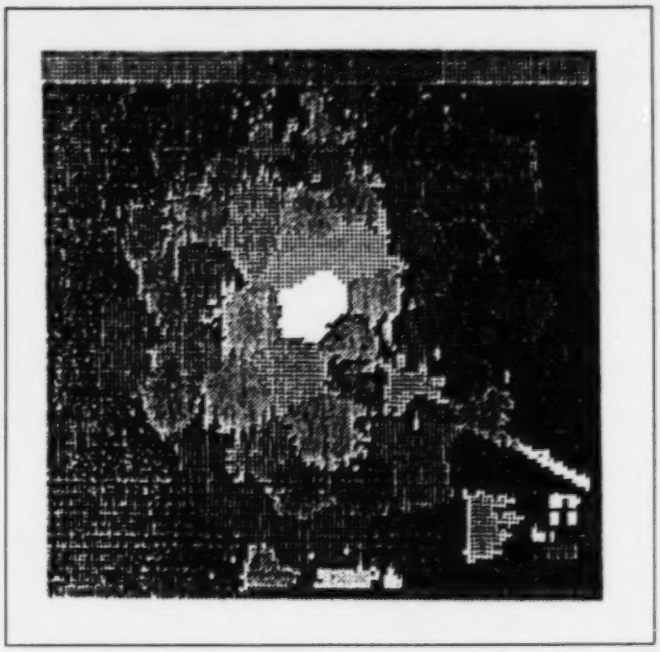

Figure 19 K-means After 5 Iterations

After few more considerations of the images at hand, we have noticed that a pixel of the image should also be influenced by its neighbors. Therefore, in the feature vectors we added three other components considering the three by three, five by five, and seven by seven immediate neighbors of a pixel. The results were a much better as shown in the next figures with the Isodata algorithm.

At this stage, the feature vectors are dependant on the pixel and its immediate neighbors. This is, however, not final and more experiments on other images will have to be conducted in order to determine the best combination of characteristics to use in order to find the sought clusters.

The clustering techniques have shown to be appropriate to be applied on the marine radar images in order to find the different regions. Their visual effect is, however, very limited because a region is not only homogeneous in intensity or distance but in all components of the feature vectors. Therefore, displaying the different regions with the same grey level will not necessarily enhance the image visually. But for the final end of automatic tracking, the regions of the Marine-Vue image will be ready to be compared to other regions of the SAR image. There are, however, some disadvantages to the clustering schemes in general, namely the fact that they are based on a geometric measure of similarity; this has the effect of making all clusters take a certain predefined shape. In our case, our measure of similarity is the Euclidean distance, this will make all clusters to assume a spherical shape in the feature space. In order to clarify the

Figure 20 Isodata After 5 Iterations

Figure 21 Isodata After 10 Iterations

previous remark, we give the example where only two components are considered in the feature vector, namely the position of a pixel. In this case, the clustering algorithm will result in a certain number of almost circles in the image. In the case where other features are considered in the clustering algorithm, the feature space will be segmented into multidimensional spheres which results in one shape of preference in the two dimensional image. This is obviously an undesirable effect in our case, because not all ice floes have the same shape. Because of the previously mentioned secondary effects of clustering, we implemented relaxation on clusters.

3.2.2 Relaxation Labeling on Clusters

The idea of relaxation has been explained in an earlier report when the relaxation labeling on edges and curves was applied on the raw marine radar image. The idea of grouping certain pixels based on a similarity measure is the fundamental core of clustering methods. But clustering in general causes certain imposed shapes to appear in the image. In order to readjust the image or redistribute it in a more independent-of-shape fashion, a relaxation labeling scheme is employed. The idea is simple, every pixel in the image has different labels with probabilities associated to them. The labels represent all the different clusters that one pixel can belong to, plus the possibility of being an independent pixel (considered to be noise in our case). As an initial guess for the relaxation labeling process, the result of the clustering algorithm is used. The centre of a certain cluster has assigned to it a high probability of belonging to that cluster in question. As a point gets further from the centre of the cluster to which it belongs, its probability of belonging to that cluster decreases and its probability of belonging to a neighboring cluster increases. The probability of belonging to a certain cluster is never zero at all points of the image in order to give rise to all possibilities. These probabilities are then updated at every iteration of the relaxation process based on a compatibility function. The compatibility function relates one label to another. Therefore, if two clusters are close to each other in the feature space they are assigned a high compatibility value. This compatibility function can even be negative, this means that the two labels are not compatible and will even affect each other in a negative manner. It is very hard, *a priori*, to find the best compatibility function to use in our particular case. This will be determined in the next phase of the project, when many trials on different images will be conducted. At this moment, we only considered the distance in the feature space in order to define the compatibility function between all labels. The result is rather encouraging, as shown in the next figures where the initial guess for the relaxation algorithm was the output of the clustering algorithm modified slightly in order to be able to display the probabilities assigned to the different labels. At the end of the relaxation algorithm, the final clusters do not represent any common shape in the image and define different regions of the image.

Relaxation in general is very dependant on the compatibility function being used. The choice of a 'bad' compatibility function can have very undesirable effects on the image. Therefore, a lot of testing is needed in order to decide on the nature of this compatibility function.

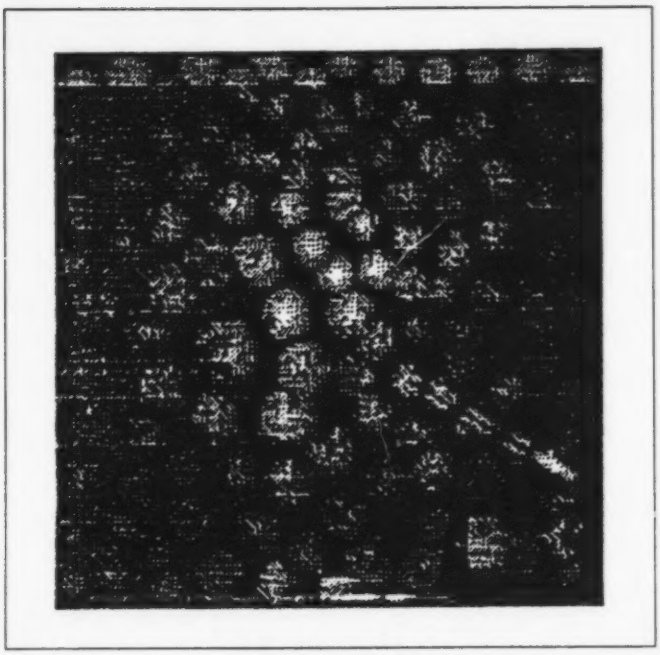

Figure 22 Initial Guess for Relaxation on Clusters

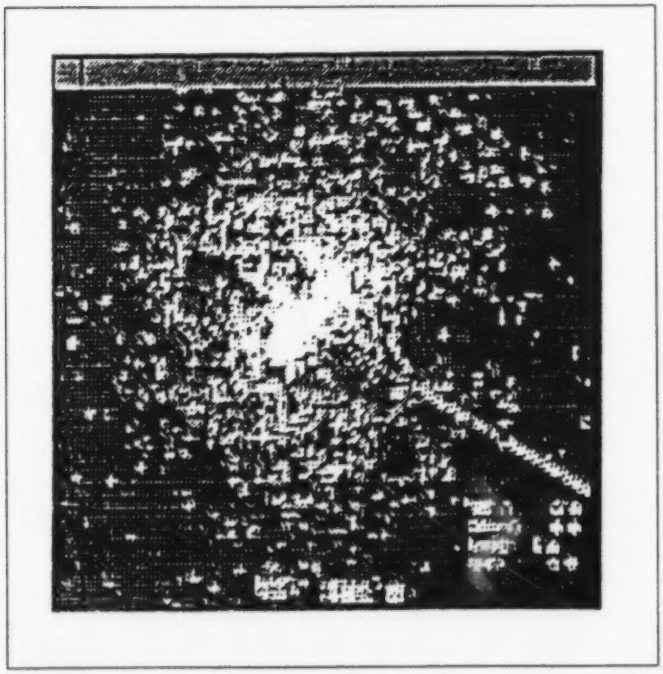

Figure 23 Relaxation on clusters: Iteration 10

If the relaxation labeling scheme is chosen at any stage for the final implementation, it will be implemented in hardware. This will considerably increase the speed, because the relaxation labeling process can be conducted in parallel over small windows.

Finally, the next issue to consider when dealing with relaxation labeling is the measure of the convergence of the algorithm. This will depend on the context in which the relaxation labeling process is used. If the relaxation is used for the end of visual enhancement, the termination of the algorithm can be decided by the user. The user will stop the algorithm once a visually acceptable result is obtained. In the case of automatic tracking, a measure of validity of the result or a measure of convergence will have to be implemented.

3.2.3 Quadtree

The quadtree method is a parallel region splitting algorithm that can be applied on the marine radar images in order to get a more clear and better approximation of the dot clusters. Quadtree representation is based on a recursive subdivision of the image into quadrants. A quadrant can assume three possible states: empty, full or partially full. If the quadrant is full or empty, no further subdivisions are needed; the grey level of the quadrant is set to the average value of its intensity if full, or to zero if empty. In the case of a partially full quadrant (or partially empty), further subdivisions are needed. This procedure is carried until either all quadrants of the image are either full, empty, or a certain pre–specified resolution of the quadrants is reached; in the latter case the quadrant can be set to either full or empty. Practically speaking, we found that the small quadrants which reached the minimum resolution should be set to empty in order to give a better visual result.

There are many ways to implement the decision process, *i.e.* deciding on the state of a given quadrant. One method that we employed assumes that the quadrant presents a Gaussian distribution of its dots with respect to the grey levels present in the image. The decision is then made based on the average and the standard deviation of the distribution. There are also some parameters to adjust in order to make the quadtree method function properly. At this stage, the intervention of the user is needed in order to specify the values used as threshold in order to make a decision the quadrants. During the final implementation of the algorithm if chosen, the decision process can be automated and adapted to the image to be treated. The next figures present results from the quadtree representation of the images. A median filter had been applied on the images after the quadtree in order to smooth the jagged output.

The quadtree representation showed desirable results as a means of visual enhancement. There is, however, one problem with the quadtree representation, namely, the fact that the output does not give any information about the regions themselves but instead only enhances the image for the human eye. Therefore, if this method is to be used for the automatic tracking end of the project, more processing will be needed to merge regions together and find specifically the different regions of the image in order to extract the features to be compared to features extracted from the corresponding SAR image. This processing consists of merging the similar regions or pixels.

Figure 24 Quadtree: Weak Decision–making Process

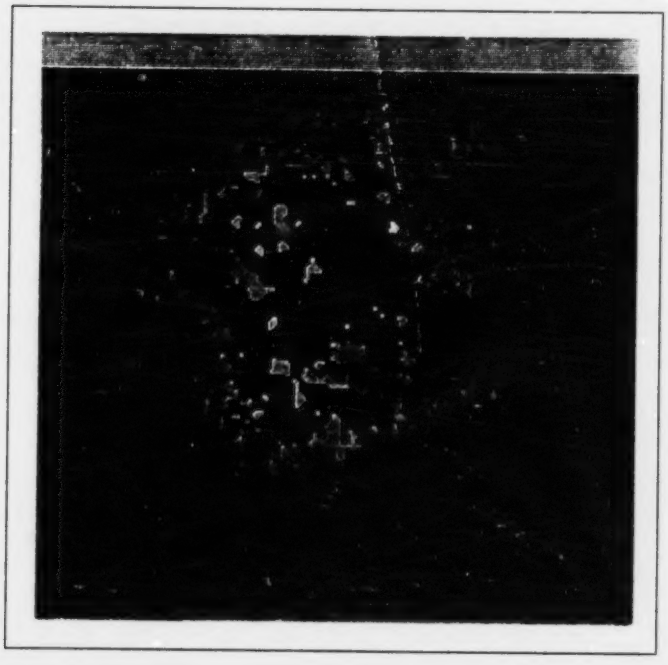

Figure 25 Quadtree: Better Decision–making Process

3.2.4 Region Merging

Region merging is a process in which one begins with an image array and ends with a set of regions [Pavlidis 1, Pavlidis 2]. The idea of merging or splitting an image is very general and many possible implementations are known in theory. In the region merging method that we implemented, we assumed a certain definition of what a region is: A region is an area of the image in which the statistical distribution of the grey levels is reasonably uniform. This is, however, not the definition that will be used for the final implementation since the whole feature vector should be used rather than the grey level only. Regions are merged together or pixels are merged into regions when the merging process does not affect "considerably" the uniformity of the two candidates of the merge. The implemented region merging technique is sequential and requires only one pass over the image in a raster scan fashion. This has the advantage of being suitable to be implemented at the scan converter output. The decision is based on the comparison of the coming pixel with the distribution parameters of its neighboring regions in order to determine whether they are similar or not. If the pixel is similar (i.e. does not modify considerably the distribution parameters of the region if it were included in the region), then the pixel is merged. Otherwise, the pixel is made into a region by itself. After each merge, the distribution parameters of a region, if modified, are updated. The process continues until the whole image is processed. There are many parameters to evaluate before obtaining a final implementation of this algorithm. The first set of parameters concerns the decision process and is composed of the parameters that affect the decision–making about the similarity or not similarity between two regions. The other degree of freedom that we have in this algorithm is the regions to consider for the test once a pixel is given. At this stage we only considered two regions, namely, the region to which the previous pixel belongs and the region to which the above pixel in the image belongs. This is so in order to assure the four-connectedness of the regions. The effect of the choice of other regions as candidates is still to be considered. We should point out, however, that the sequential implementation of the algorithm causes the resulting image to be skewed. This is due to the fact that the decision if a pixel belongs to one region or another is based on the closest already existing regions.

The next figures present some of the results that have been obtained under the assumptions made above, (i.e. four connectedness and the amount of statistical parameters considered, namely the average and the standard deviation).

The results obtained from the region merging algorithm confirm the fact that the marine radar images should be treated as images presenting clusters of dots rather than boundaries. Moreover, this region merging algorithm gives rise to the possibility of being able to visually enhance the image as well as being able to segment the image into regions. There are, however, some problems such as: the regions are not necessarily found separately, two of what we expect to be regions can be merged together under the decision–making process at hand, as well as one real region can be split in many regions under the same decision–making process. We, therefore, expect many trials to be conducted in order to be able to determine the best decision–making

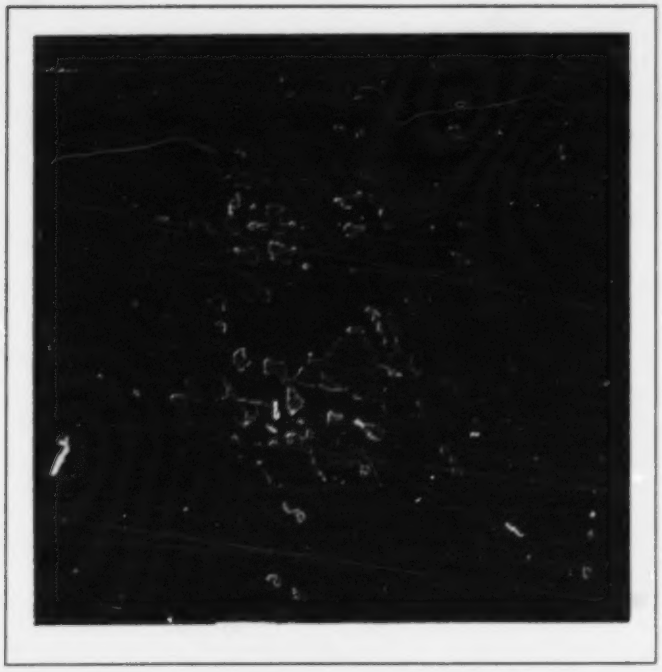

Figure 26 Region Merging: Weak Decision–making Process

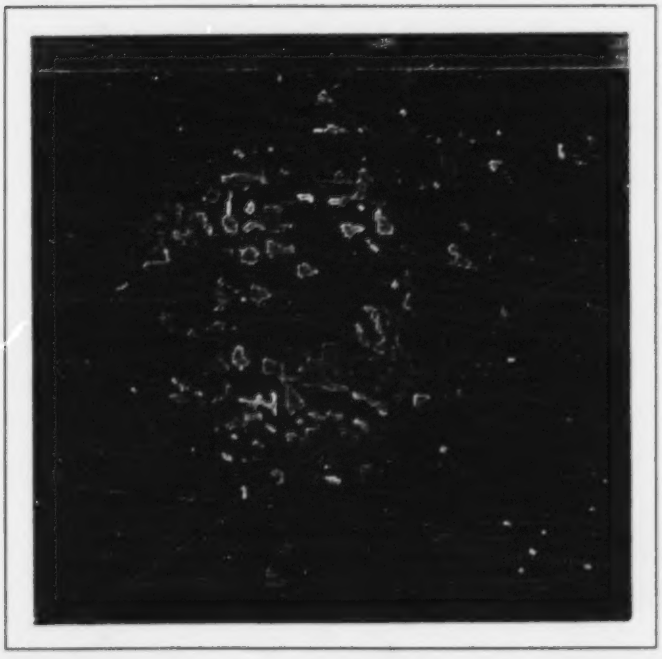

Figure 27 Region Merging: Better Decision–making Process

process and we also expect other algorithms to be appended to the region merging algorithm in order to diminish the effect of making an error.

3.2.5 Summary of the Results Obtained from the Region–Based Techniques

The region–based techniques have shown good visual enhancement of the marine radar images. The two methods that were most suitable for visual enhancement are region splitting (or quadtree) and region merging. There are, however, many parameters to adjust in order to achieve the best enhancement possible using those methods. For the visual enhancement aspect, the user will interact with the system, thus changing the parameters, in order to enhance the image. There are many combinations of algorithms that will yield to a visual enhancement system. The best combination is still to be determined. Moreover, two methods have been implemented in order to find regions in the image, this will not necessarily result in a visual enhancement of the image; but will be start for the final end of automatic tracking of the ship in the ice infested waters. The clustering method followed by a relaxation labeling process on the clusters has shown to be quite suitable for region or cluster finding. There are however no conclusive results concerning the automatic tracking, because this will need the region or feature extraction from the corresponding SAR image.

4. Discussion

There were three major steps in this project, namely, the development of pre-processing and post-processing, edge–based, and region–based algorithms. The pre-processing and post-processing algorithms were developed after some statistical studies over the marine radar images at hand. Many algorithms have been developed under this category—some of them proved to be useful at some stage of the processing, others did not present any promise. The same judgement applies for the edge and region–based algorithms that were developed. Some results were presented in this report in order to further enhance the understanding of the effect of certain algorithms over some given images. A global result of the enhancement of the marine radar image is not obtained yet and will be sought during the second phase of this project, where, many trials of different combinations and variations of the algorithms explained above will be conducted over different radar images. It is still difficult to confirm at this stage of the project the best combination of processes in order to achieve the enhancement of marine radar images. This step will be conducted in conjunction with the personnel of `Canarctic Shipping`. We have, however, come to the conclusion that the marine radar images need to be pre-processed before using any edge or region enhancement method. This pre-processing will include some or all of the next techniques: low pass filtering (average, median, *etc.*), edge preserving filtering, mathematical morphology. Edge–based segmentation techniques in general did not show promising results of enhancement for the marine radar images at hand. The region–based techniques that have shown best visual enhancement are a variation of region splitting (quadtree) and region merging. The region–based techniques that have proven to be suitable for the final end of automatic tracking are composed of clustering (region growing),

relaxation labeling on clusters and region merging. During most of the report, we have shown the results of individual algorithms when applied on the raw marine radar image. There was, however, no major enhancement shown in the previous images since this involves a combination of algorithms that will be determined during the next phase of the project. At the end of the present phase of the project, we have tested combinations of algorithms that have shown good enhancement according to the personnel of `Canarctic Shipping`. We have included several of `Canarctic Shipping` recommendations in appendix "A". The next image shows a result of applying a region splitting algorithm a the raw marine radar image, after which a median 3×3 filter is applied followed by an edge detector.

Figure 28 Quadtree-smoothing-edge detection

The next image involves applying morphology on the marine radar image in order to further enhance the contours that define the ice floes and eliminate the scattered noise. The second step involves applying a region splitting procedure followed by region merging. An edge detector is then convolved with the resultant image after which the resultant image is overlaid on the original image. The result is an enhancement of the existing ice floes as shown below:

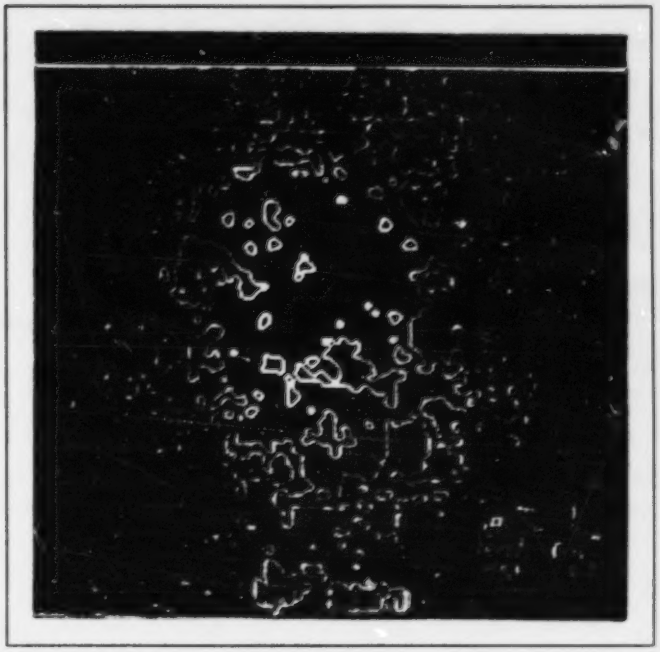

Figure 29 Morphology-Quadtree-Region Merging-Edge Detection-Overlay

5. Hardware and Software Specifications

The software developed in order to demonstrate the feasibility of using image processing techniques explained above was all developed by `Cimmetry Systems` and was mostly written in the "C" programming language. The source listings of the different image processing algorithms are included in appendix "B". Some graphics facilities were written in Assembler in order to speed up the displaying process. The software was not designed to be a commercial package, but was, rather, developed for testing the different algorithms. Therefore, it might not be an error free package, but it is user friendly enough in order for it to be used by a new operator.

The compiled software by itself is quite large, moreover, when running the program, two images (inputoutput) of 256×256 are desired. However, the Dos operating system imposes a 640 KB limit of active memory. For, this reason, `Cimmetry Systems` developed a software module in order to overcome this difficulty imposed by Dos. This module permits the software to take advantage of available extended memory on the system.

The Software runs under the Dos operating system and requires a VGA graphics card with a multi–synch monitor. If the user has the source code, then the software can be compiled in order to take advantage of the math co-processor or not.

6. Conclusion

In the final report of Phase V of the Shipboard Ice Navigation Support System (SINSS) one recommendation put forward by Canarctic Shipping Ltd and the Transportation Development

Centre was to investigate the use of signal processing techniques in order to improve the quality of the MARINE–VUE display of marine radar images. To this end, Cimmetry Systems has developed and tested a wide variety of image processing algorithms on the marine radar images. In order to evaluate the results of these algorithms and to identify the most appropriate ones, two goals of this project have been kept in mind.

The first goal of the project is to develop a marine radar display system that will allow an experienced operator to be able to efficiently position the ship on the corresponding SAR image. To this end, this phase of the project studied the feasibility of using image processing to improve the quality of the marine radar display—this was called enhancement throughout the report. The second goal of this project is to study the feasibility of automating the procedure of positioning the ship on the SAR image. To this end, we studied methods that were able to segment the marine radar image in order to identify ice–floe feature. These features can then be matched with similar features derived from the SAR image in order automatically correlate the two images.

With these two goals in mind, below, we summarize the utility of each algorithm that was considered in this project. We divide the methods into three broad classes, pre/post-processing methods, edge–based methods and region–based methods:

Pre- and Post- Processing Methods.

The pre-processing methods described below are equally applicable for image enhancement and automatic tracking.

Average Filter: This method has the undesirable effect of blurring the image too much, and hence, it is not recommended.

Median Filter: This noise-removal filter is superior to the average filter since it retains more edge–features in the marine radar image.

Edge–Preserving Smoothing: This is an enhancement of the Average Filter. It is a superior method that is capable of removing noisy features and smoothing the image, without blurringit. It is recommended that this algorithm be retained.

Frequency Domain Smoothing: This method has the disadvantage of being too global. This causes it to be difficult to control and to take into account local features. This method is not recommended.

Mathematical Morphology: Since the marine radar images have poorly defined boundaries, we recommend that this method be kept. It can be used to close and better define the boundaries.

Histogram Treatment: The marine radar images did not present sufficient variation in gray–levels to warrant histogram–based methods.

Thresholding Methods (Average/Otsu/Adaptive): The simple thresholding of the marine radar images gave very poor results, and is therefore, not recommended. Thresholding the gradient image, did not show good results at this stage, but should be retained in order to be applied after suitable segmentation.

Edge–Based Methods.

The edge–based methods described below are more suited for the enhancement of the marine radar images. Note that there are two ways in which they can be applied. First, they can be applied directly on a suitably pre-processed images in order to perform edge–enhancement and segmentation. They can also, however, be applied after the region–based methods in order to highlight the boundaries of the regions. Although some of the methods described below yield poor results when applied directly on the marine radar image, they should be retained for further consideration as they can yield favorable results when applied after an appropriate region–based method.

Convolution Operators (Prewitt, Sobel, Laplacian, bi–Laplacian *etc.*): These are simple edge–detecting operators. They yield poor results when applied directly on the marine radar image because of the high noise content in the images, as well as the fact that boundaries in the image are ill-defined. We, however, recommend that the Sobel and Laplacian operators be retained to highlight ice–floe boundaries after the application of a region–based method or after a pre-processing technique such as edge preserving smoothing, as they showed to be more robust and noise–resistant.

Transform Methods: Enhancement algorithms based on transform methods did not show good results because of the lack of local control and the high noise content in the images.

Relaxation labeling for Edge and Curve Enhancement: This method was developed as an enhancement of the simple operator–based edge detector because these methods had the disadvantage of being very sensitive to noise. This method iteratively, takes into account neighborhood information, in order to remove noise and enhance edge–features. It yielded favorable results in the preliminary trials that were performed in this project. These results were, however, not suitable enough for a full segmentation with a contour tracing algorithm. This method is, thus, only suitable for the visual enhancement of the marine radar images.

Region–Based Methods.

Many of the region–based methods developed showed potential for the enhancement of the marine radar image visually as well as the determination of the ice floes for automatic tracking.

Clustering (K-Means and IsoData): The clustering methods developed showed fairly good results for the segmentation of the marine radar images and finding ice–floe features in order to match with the corresponding SAR image. They were not, however, suitable for visual enhancement. More work is required in order to determine the most appropriate feature vector to represent the marine radar images.

Quadtree: The quadtree method is an application of region splitting. The marine radar image is recursively subdivided, based on the density of dot–clusters. This results in a good visual enhancement of the image. In order to segment the image, to identify ice–floe features, the quadtree'd image must be further processed. Region merging (described below) was implemented, in order to group together and properly define the regions.

Region Merging: Region merging is a method that groups together pixels or regions that have similar characteristics. This method was developed after it was observed that the quadtree method yielded good visual enhancement. Region merging is then used to group together and classify the pixels as distinct regions and entities. In itself, region merging does not produce a very good visual enhancement, but it is recommended as an algorithm that can be applied towards the automated positioning of the marine radar image on the SAR image.

Relaxation labeling on Clusters: The clustering methods tended to converge and prefer predefined geometric shapes. For this reason, a relaxation labeling algorithm on clusters was implemented. This results in a complete segmentation of the image, however, at this stage it cannot be used to visually enhance the marine images. The combination of the relaxation and clustering algorithms result in a large number of parameters that must be tuned. This will have to be carried out in the next phase of the project.

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8. Appendix A: Technical Reports from Canarctic Shipping

The following appendix contains the comments and technical reports submitted by Canarctic Shipping during the course of the project.

CANARCTIC
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September 12, 1988

Mr. Faycal Kahloun
Cimmetry Systems Inc.
8300, Chemin Cote-de-Liesse
Suite 104, St.-Laurent, QUE H4T 1H1

File: 4869-A

Dear Faycal,

Subsequent to our visit to Montreal last week, the following comments should help in future developments.

Cimmetry presented to the assembly a short summary of the work that had been performed up to date and a quick technical explanation of the analysis techniques that had been implemented. Examples were given of the results of selected transformations on recorded images to illustrate the reasons behind research orientation decisions that were taken.

Of the selected analysis methods that were to be developed, Quadtree was one of the last to be addressed. Because of unknown image properties that became apparent after preliminary analysis, this method along with others of the same family, will become the prime focus of development. The clearly demonstrated superiority of Quadtrees at extracting the sought after visual information, was the main reason for the change of orientation of future developments.

Parallel to these findings, we were made aware of the problems associated in working in the DOS environment. The memory allocation problem has plagued the smooth development of software up to this point. Special efforts will be invested in solving this annoying problem that shows up when calls to memory space are made beyond the normal DOS environment limit. Either special routines will have to be written or the operating system will have to be changed to OS-2 with the associated high memory requirements. A decision on that matter should be reached in the days to come.

In general, the project seemed ahead of schedule with significant results already available. What were believed to be more adequate images out of the originals supplied by Canarctic, were chosen for future work, to help correlate the results with the associated SAR imagery. One promising technique in the interpretation of the results of the processing, seems to be the overlaying of the original picture with the transformed one to slightly enhance features that would not otherwise be as visible.

The presentation was greatly improved by the availability of a menu driven program that permits to call transforms and manipulate images. It is suggested that this module be somewhat refined, in order to maximize the throughput at subsequent meetings.

Canarctic is positively impressed by the demonstration and at this early stage significant results have been reached that have a potential of assisting the ice navigator in his task of finding the ship's position in the surrounding ice field.

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November 11, 1988

Cimmetry Systems Inc.
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File: 4869 (Cimmetry)

Mr. Faycal Kahloun,

Re: Phase I Canarctic Review of progress
Feasibility of Using Segmentation Techniques
for the enhancement of Marine Radar Images.

Following Canarctic's second visit to Cimmetry , the following report reflects our observations on the recent developments. At this point, most of the requested software has been written and the latest additions consist of:

Mathematical morphology
Clustering
Relaxation
Improvements to quadtree

Many algorithms of these overall methods have been developed. Early analysis of selected images, revealed the need for variations of region based techniques such as; region merging and pyramid structure closing method, also the split and merge analysis method.

The earlier memory problem was resolved and corrected in most of the software. Many convolution facilities and masks were developed, as well as improvements to the general display and interface program.

Selected results from transformation methods were demonstrated and discussed. Most of the software methods were tried and the demonstrations were functionally conclusive.

The region merging method was demonstrated, having similar properties to quadtree, result wise, but being sequential region based. The same image was treated twice for many iterations but with different parameters each time. The results were dramatically different, having very poor results the first time, but highly meaningful results the second time. This technique being region based, could be used in auto-tracking applications. The widely different results obtained with the two sets of parameters, emphasize the fact that early results cannot be used to judge a method in the negative sense and that a lot of evaluation work based on trial and error remains before truly conclusive results can be obtained.

The relaxation on clusters algorithm was demonstrated, in which the image was pretreated by the KMEANS clustering method, as a starting point for the algorithm. This method yields region based results that could be used for auto-tracking but was of no noticeable significance for visual enhancement even though the tendency of the algorithm was to recreate the original image, using property defined regions. These regions could possibly be used for some sort of visual enhancememt to be determined in the future.

The relaxation on edges and curves method was also demonstrated. The results were visually significant and offer a real improvement from the raw image. Since this method is not region based, the potential for auto-tracking application is relatively limited.

The relaxation on intensity was then demonstrated, with no significant results. Since this method requires long iteration times, there was no time to try to adjust the parameters to yield better results. The potential of this method remains to be demonstrated.

An attempt was made to demonstrate the enhanced quadtree method, but memory problems with this particular method, defeated the demonstration. Partial results were obtained, but more iterations would have been needed to evaluate it.

It is still too early to give any appreciation of any method in particular, since most of the evaluation work is still to come. However, of the demonstrated methods, two seemed to have a very good potential for valid results. The relaxation on edges and curves seemed to yield satisfactory results in visual enhancement, even at this early stage. Since many parameters have to be set before using this method, the possibilities are largely untapped. The other method offering promise is region merging. This method yielded feature delimited enhancement once superimposed on the original image.

Another method that showed interesting results, was region merging. The results are similar to those obtained with quadtree, but with the added region definition information.

Apart from the memory problems caused by the increasing size of the software (different from memory allocation problems for image storage), the software seemed to be sufficiently flexible and special efforts have been made to promote access to different images and method piping.

At this point of the project, the results obtained indicate clearly the potential for image enhancement. Phase two of the project, which deals with the full trial of the developed methods, should confirm their usefulness for image enhancement.

One potential that is clearly emerging, is the possibility of developments in the area of auto-tracking and further project definitions to initiate developments in this direction would be needed.

Even though essentially the same software would be used for both applications, the requirements are different and thus the choice and value of the parameters will be different. In both applications, the goal is to enhance a particular set of features to permit visual correlation with SAR in one case, and digital feature correlation with SAR in the other case.

The range of feature attributes that can be used for automatic tracking is much greater than what can be used for visual enhancement. For instance, feature moments calculations are totally useless for visual enhancement, but extremely useful for automatic tracking purposes. The requirements for visual enhancement are more restrictive than the ones for auto-tracking. This emphasizes the fact that the two goals require separate developments, and that as much time will be needed to develop methods for either application.

The development of the two applications must be supported by proper evaluation, testing the methods on real images. In the case of visual enhancement, the process is relatively straightforward and entails comparing the enhanced image with the SAR image to determine if the transformation helps in identifying features.

The evaluation of the auto-tracking transformations on the other hand, requires that the transformed images be digitally compared not with the SAR image, but with the transformed SAR image.

In fact, the features and properties extracted from the radar image, must be compared with the equivalent information on the SAR image.

Whereas the evaluation of the transformations for the radar image can be undertaken at this point, the same cannot be said of the transformations for automatic tracking. The transformations for visual enhancement can be developed unilaterally since the SAR visual information is the non-changing reference set that constitutes the model. In the case of auto-tracking, there is no fixed reference to model on. Both sets of transformations, for the radar image and for the SAR will have to be developed concurrently. What must be found, is the set of features or properties from both images, that can be enhanced or extracted in order to be mutually compared for eventual matching.

The difficulty will result from the fact that the two images, apart from relating to the same thing, have totally different properties. New software will have to be developed for SAR analysis, even before transformations on the radar image for the purpose of auto-tracking can be attempted. There is clearly a need for both, but they are complementary in nature. In fact, auto-tracking will probably need an initial fix, that visual enhancement will help provide and in return, autotracking will significantly extend the life of a fix obtained with the assistance of visual enhancement.

The recent demonstration also revealed that execution speed may have a significant bearing on the evaluation phase. Since the methods have to be implemented in software until the selected ones are implemented in much faster hardware, some of the methods require extremely long periods for results to be available. Typical delays are in the range of 12 to 20 hours for a reasonable number of iterations.

For the demonstration, three methods had to be started the day before in order to have results available. It should be noted that in two of these methods, the images had been reduced to shorten the processing time. Software has been developed for at least 5 analysis methods, with variations to each. For each method, a number of parameters are to be varied to yield the best results. In addition, three or four methods will usually have to be pipelined, in varying sequence, in order to achieve the desired results. This in turn will have to be repeated for the 20 or more images that will be available for analysis. The number of possible combinations are staggering and albeit the choice of combinations and the fine tuning of the parameters will be guided by insight and experience, time will be of concern.

To summarize, more software has to be written to analyze the SAR images for the purpose of auto-tracking technology developments. It is believed that the development of SAR analysis methods will require as much time as will be required to develop radar image analysis methods. Furthermore, radar image analysis software for auto-tracking, cannot be evaluated before SAR analysis software has been developed.

The execution time required for the different methods, prompt the recommendation that Cimmetry allow more time in phase II than is requested in their present proposal. A additional period of 5 weeks would appear reasonable. The time constraint might be lightened by the use of several machines concurrently.

We believe the project has reached the most interesting stage, in the sense that true results are beginning to be available. Future developments promise to be most interesting.

Charles Gautier,
Project Engineer.

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December 9, 1988

File: 4869A (Cimmetry)

Re: Phase I Canarctic Review of progress
Feasibility of Using Segmentation Techniques
for the enhancement of Marine Radar Images.

Dear Fayçal,

Please find included, a copy of the progress report from the third visit of the project, and an the corresponding invoice. This is the third of five planned such visits and the last ones are planned for mid December.

Because of the unavailability of Mr. Bob Gorman at the time of the last visit, Mr. Alan R. Sneyd had replace him. However, the rates charged for Mr. Gorman are different than the ones charged for Mr. Sneyd, the latter being higher. Consequently, the invoice for this visit reflects this situation and has been set at $3,000.00 instead of the agreed $1,500.00. Please do not hesitate to contact us, should you have any questions.

Yours truly,

Charles Gautier

Charles Gautier
Project Engineer

Phase I Canarctic Review of Progress
Feasibility of Using Segmentation Techniques for the Enhancement of Marine Radar Images.

1.0 Introduction

Cimmetry systems is conducting a project to test the feasibility of using computer vision segmentation techniques for enhancing marine radar images to assist in ice navigation.

Canarctic was subcontracted for this project to provide guidance and general evaluation of the software developed for enhancement. A total of five (5) visits were originally planned and this report summarizes the observations made on the third visit.

Present at this meeting held at Cimmetry Systems Inc. in Montreal; Maurice Audet TDC, Fayçal Kalhoun Cimmetry, Ajit Nilakantan Cimmetry, Alan R. Sneyd Canarctic and Charles Gautier Canarctic. This meeting was held on Tuesday November 2, 1988.

The goal of this visit was to evaluate the latest software method to be implemented under the project, and provide input in the proposal for Phase II of the project.

In order to ensure that everyone present had an updated picture of the results provided by each method, a representative set of methods were demonstrated to the group. Also, because of memory problems, the quadtree method could not be demonstrated at the last visit and was therefore tried anew.

2.0 Results and Discussions

2.1 Demonstrated Methods

The demonstrated methods were:

- Quadtree
- Vary-Quad
- Mathematical Morphologie
- Clustering (Isodata, K-means)
- Relaxation (on clusters and on edges)
- Region merging

The Quadtree method was demonstrated in conjunction with other processing methods. The quadtree was run on the raw image, the result was averaged then convoluted with the Bi-Laplacian to find the edges. The resulting edge map was overlaid on the original image to visually enhance the image features. The results were very good and substantial enhancement of certain features was obtained. At this point, the detected edges mostly correspond to what would be naturally detectable with the naked eye, even though a few outlines did not correspond to natural features.

The Vary-Quad method was demonstrated with a similar processing sequence. This method is a variant of the Quadtree method but utilizes gaussian distribution for decision making. The method is slower than Quadtree because of the added decision stage in the processing. The results were very good, with better definition of the features and edges.

Mathematical Morphologie was demonstrated on a selected radar image. This method will be used mainly at this point, to prepare the image for further processing. The net effect of this method, is to increase region definition and enhance weak features by connecting neighboring pixels and re-enforcing groups of pixels.

Two clustering techniques were demonstrated with varying degrees of success for visual enhancement. The first method, K-Means, uses position and intensity information to group pixels into clusters that form regions. The number of regions has to be defined prior to processing and the method will essentially shape the regions as best as it can. The second method, Isodata, uses position, intensity and neighboring pixel information to form clusters. The added decision information used in this method allows it to automatically adjust the number of regions. Both methods do not seem suitable for visual enhancement directly, but show interesting properties for the purpose of automatic tracking. Both methods are good preprocessing methods to use before Relaxation on clusters, but the Isodata version provides a better starting point because of the adaptive number of regions.

The Relaxation on clusters method, uses predefined regions as a starting point, usually determined by clustering methods. This method delivers results that are not meaningful for visual enhancement, but that can be used for automatic tracking. The processed image is visually similar to the original image, except that it is defined as regions and not individual pixels. These regions can be used to identify image features something that cannot be done easily from the original image.

The Relaxation on edges method was applied to the original image without preprocessing. This method attempts to define edges by grouping statistically self re-enforcing pixels. The net result is a gradual disappearance of isolated pixels, and a gradual re-enforcement of the ones that are part of an apparent cluster or line of pixels. The visual enhancement was very good, and significant improvement of the original image was obtained. This method would be of limited use for automatic tracking purposes because no region information is produced.

The Region Merging method, as the name implies, is a region based technique, that attempts to include subsequent pixels in turn in the current region, based on the properties of the adjacent pixels and the current region. The results can be displayed in regional increments and the picture is built up to the desired appearance by successively calling more regions on the display, until the display is satisfactory. The resulting image can then be processed further. The visual results are similar to the ones obtained with Quadtree and have a potential for significantly enhancing image features. Since this method is region based, it can be used for automatic tracking.

2.2 Discussion

At each visit, a substantial improvement in the managing software can be noted. Apart from the newly developed methods, earlier problems have been solved and very little of the original bugs remain. All the memory problems inherent to the DOS environment have been bypassed and the system is now fully functional.

Most of the demonstrated methods had been tried before and little was learned from the demonstration. However, as stated in previous reports, adjustments of the parameters will have a significant impact on the results of a processing method.

This is very apparent when the results of the first visits, for the same methods, are compared to the last results. A combination of sequential processing by different methods, and further adjustments to the operating parameters with values obtained through experience during the project, have improved the results that can be obtained from a processing method. This shows how important the evaluation Phase of the project will be in terms of validation of a method.

3.0 Conclusions

The software development is mostly completed and very little else than reporting remains. The software seems to offer good potential for image enhancement and preliminary results have been obtained that support further work.

As part of this third visit, Canarctic was requested to evaluate the proposal from Cimmetry for Phase II of the project. After review, it is recommended that at the end of Phase II, prior to the Final Software Testing, Canarctic be trained for a period of two days, on the different methods developed. This training period will allow us to fully evaluate the potential of the algorithms and help us make a decision on the usefulness of the methods. A revised cost proposal was forwarded to Cimmetry for that purpose.

CANARCTIC
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January 13, 1989

File: 4869A

Mr. Faycal Kahloun
Cimmetry Systems Inc.
8300, Suite 104
Chemin Cote de Liesse
St. Laurent, Que.
H4T 1H1

Dear Faycal:

Re: MARINE-VUE Enhancement Program Phase I

Please find enclosed a copy of our progress report on the meeting held at your office on December 21, 1988.

This report is the fourth and final report for our contribution to Phase I of the MARINE-VUE image enhancement program. Also included with this delivery is our final invoice relating to the above mentioned contract.

As mentioned in the report, we feel significant results have been obtained from the use of segmentation techniques for enhancing marine radar images for ice detection. We feel that the feasibility objective of this project has clearly been met and we look forward to future developments in this regard.

In Charles's absence, please direct any questions you may have on the enclosed report to myself.

Yours truly,

Robert Gorman
Research Scientist
Operations Development

RG/tg
Encl. REPORT
INVOICE

Phase I Canarctic Progress Review
Feasibility of Using Segmentation Techniques for the Enhancement of Marine Radar Images

1.0 Introduction:

Cimmetry Systems is conducting a project to test the feasibility of using computer vision segmentation techniques for enhancing marine radar images to assist in ice navigation.

Canarctic was subcontracted by Cimmetry to provide guidance and general evaluations of the software for image enhancement at various stages during the contract. This report represents the summary of observations made by Canarctic during the fourth and final visit.

The final meeting was held on Wednesday, December 21, 1988 at Cimmetry Systems office in Montreal. The following individuals were present at this meeting: Maurice Audette (TDC), Faycal Kahloun (Cimmetry), Agit Nilakantan (Cimmetry), Charles Gautier and Robert Gorman (Canarctic).

2.0 Objective

The objective of the visit was to observe the final image enhancement software package developed by Cimmetry for the Phase I program. This report presents Canarctic's review of the image enhancement software.

3.0 Results and Discussions

The final software package developed by Cimmetry was demonstrated. The most significant attribute of the software modifications over previous visits was the ability to combine multiple enhancement packages and vary the parameters of one package over another. In addition, several new image

manipulation utilities were developed, the most important being a new method for zooming images using linear interpolation. The user interface for software selection was improved by the addition of an active screen cursor controlled by a trackball mouse.

The first image enhancement demonstrated was edge preserving filtering. This method is based on conventional filtering techniques which selectively smooth parts on an image based on the presence or absence of an edge. The edge preserving filter computes the variance between neighbouring pixels and averages the pixels within low variance regions thus highlighting potential edges or boundaries. The result of the filter was a general smoothning of the "inside" of features with all edges preserved.

The second image pre-processing enhancement demonstrated was mathematical morphology. This method is used to re-enforce salient features within the image and delete random elements such as single bright pixels that are separate from any other feature. The probability that single bright pixels are not associated with relevant features such as a lead or large floe edges is high and should be considered as noise elements in the image. In simple terms, the mathematical morphology algorithm expands an image by doubling lines and pixels, then averages the pixels to reduce the image back to the original make-up. The result of this process is that gaps in the larger well defined features are filled in such as along a lead edge. This results in "cleaned" edges and the general smoothness and appearance of the image is improved.

The most significant attribute of mathematical morphology noted during the demonstration was when the method was preceeded by edge preserving filtering. The combination of begining with edge preserving filtering followed by mathematical morphology

allows for the beneficial characteristics of each method being added to improve the edge enhancement of the image. This improvement in image edge enhancement is an important pre-processng method undertaken prior to quadtree or relaxation algorithms.

The linear interpolation zooming algorithm developed by Cimmetry was demonstrated. Unlike conventional methods of zooming which employ pixel duplication to achieve the zoom effect, this method performs linear interpolation in all directions for each pixel to determine the optimum value for the newly created pixels. The product is a clearer image that does not have the blocky appearance that results from conventional pixel duplication zooms. The added benefit of linear interpolation zoom is that a very broad range of magnification is possible without a significant loss of geometry. This results in the preservation of potential edges in the image, critical to subsequent analysis by methods such as quadtree.

The final demonstration of the meeting involved a combination of a number of enhancements that terminated with a quadtree type analysis of the marine radar image. The edge preserving filter was first applied to the image, followed by the mathematical morphology transformation. Once this was completed each section of the image was zoomed using the linear interpolation function and a quadtree analysis was performed on the zoomed section. Once processed, the individual picture section was zoomed back to the original size and the next section was zoomed. In this manner, the complete original image was processed.

Three magnification factors were tried, each producing an image with different characteristics in terms of identified regions. The lower the magnification factor, the less the

identified regions corresponded to visually identifiable features. However, it was difficult to judge the merits of one result versus another since the comparison of the SAR information to the radar image was not available for the demonstration. A close examination of the processing results, compared with the SAR imagery, would reveal the optimum zoom level.

A significant component of the demonstration was that the linear interpolation zoom and quadtree analysis alone without the prior use of edge filtering or mathematical morphology produced a much poorer image then the image produced from all processes combined.

4.0 Conclusions

The radar image produced at the completion of the image analysis using the edge preserving filter, mathematical morphology, linear interpolation zoom and quadtree analysis contained many more potentially recognizable features than the original radar image. The ability to vary parameters within each step provides a wide range of manipulation possibilities that may aid the user in arriving at an image that most closely matches the SAR image for pattern matching.

The goal of the project was to test the feasibility of using several segmentation techniques for marine radar enhancement of ice features. This potential has clearly been demonstrated. What is needed now is a clearer understanding of the relationships of each combination of enhancement techniques relative to the actual ice conditions as imaged on corresponding SAR images.

Canarctic collected, in November of 1988, a large suite of digital SAR marine radar pairs, on behalf of the TDC, of ice conditions in the Canadian Arctic. It is recommended that the subsequent analysis phase proceed and that these digital data be used in the analysis.

9. Appendix B: List of Equipment

Two systems have been purchased during the course of this project. Their description is given below:

System 1

1- 386/20MHz based PC
1- 1.2 Mb floppy
1- HD 80 Mb/28ms
1- VGA card
1- Graphics monitor (640x480)
1- Optical mouse
1- 80387-20 MHz
1- Internal modem 2400 baud
1- 1Mb Ram

System 2

1- 286/16MHz based PC
1- 1.2 Mb floppy
1- HD 80 Mb/28ms
1- VGA card
1- Graphics monitor (640x480)
1- Mechanical mouse
1- 80287-12 MHz
1- 1Mb Ram